Minutes of proceedings of the Institution of Civil Engineers

Institution of Civil Engineers (Great Britain)

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SIR WILLIAM HENRY WHITE, K.C.B.

ELECTED PRESIDENT 1903

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MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CLV.

EDITED BY

J. H. T. TUDSBERY, D.Sc., M. INST. C.E., SECRETARY.

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THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1903-1904.—PART I.

SECT. I.—MINUTES OF PROCEEDINGS.

3 November, 1903.

JOHN CLARKE HAWKSHAW, M.A., in the Chair.

Mr. J. C. HAWKSHAW, the retiring President, said he had the painful duty of recalling to the members that since the last meeting they had lost a distinguished honorary member in Lord Salisbury. It was not for him to say anything in praise of so eminent a man as the late Prime Minister, whose merits were well known, as were his great services to his country; but he felt sure the members would wish to record how keenly they felt the loss which the country had sustained by the death of his lordship. He therefore moved:—

"That the members present at this meeting desire to record the sense of the loss which the Institution has sustained by the death of the Marquess of Salisbury, Honorary Member."

The resolution was agreed to in silence.

Mr. HAWKSHAW observed that the signing of the Minutes of the last Ordinary Meeting was the last official duty which he had to perform as President, and it only remained for him to introduce his successor, Sir William H. White, and vacate the chair. Really no introduction was necessary, and he felt sure the members would extend to Sir William a very cordial reception. They would rejoice that his health had admitted of his undertaking the somewhat arduous duties of the Presidency. Among Past-Presidents of the Institution there had been men who had devoted their lives to every branch of the engineering profession. The name of one, Lord Armstrong, would always be associated with improvements in armaments; but this was the first occasion on which the Institution had had a President who had been intimately associated with the first line of defence, the Navy.

Sir WILLIAM HENRY WHITE, K.C.B., President, having taken the Chair,

Sir GEORGE BRUCE remarked that he had great pleasure in moving, "That the members present at this meeting desire, on behalf

of themselves and others, to record their high appreciation of the services rendered to the Institution by Mr. J. C. Hawkshaw during the term of his office as President." He was sure Mr. Hawkshaw would not have been true to his family traditions, and to the traditions of the Institution, if he had not filled, in the way he had done, the office once held by his esteemed father. The members had every reason to believe that the traditions which had come down, with regard to the Presidents of the past, had been worthily and honourably sustained by Mr. John Clarke Hawkshaw, who had just retired from the Chair. Mr. Hawkshaw certainly had the satisfaction of feeling that he had left the honour of that Chair untarnished during the term for which he held office. He moved the resolution with his whole heart, having in mind, not only what Mr. Hawkshaw himself had done, but what his father had done before him.

Sir Douglas Fox seconded the motion, which was carried unanimously.

Mr. J. C. Hawkshaw thanked Sir George Bruce and Sir Douglas Fox for the kind manner in which they had put the motion before the members, and the members for the hearty way in which they had carried it. In looking back upon the past year he remembered shortcomings, and felt there were things which might have been better done than perhaps he had been able to do them, but the knowledge that he had the thanks of the members for what he had done softened any regret that he might have. During his term of office he had received the greatest kindness and courtesy from the whole of the members of the Institution, and especially from his colleagues on the Council; and his work as President had been lightened by the admirable way in which the work had been done for him by the staff, under the able guidance of the Secretary, Dr. Tudsbery.

The President then delivered the following Address to the members:—

In the first Charter of the Institution, granted in 1828, amongst the many branches of civil engineering which the Society was intended to promote, mention is made of "the art of navigation by artificial power for the purposes of commerce." This was 16 years after the "Comet" had commenced her service on the Clyde, and 7 years after the first iron paddle-steamer, the "Aaron Manby" had crossed the channel for service on the Seine. Nearly all the steamers in existence were employed on rivers, estuaries, canals, cross-channel or coasting service; all were propelled by paddles, and iron hulls were uncommon. In 1828 the British

Empire owned 293 steamers, aggregating 32,000 tons, and during that year 31 steamers, of less than 2,300 tons, were added to the register. The largest steamer afloat, described as a "leviathan" and "the wonder of the world," was running between London and Leith. She was 160 feet long, about 500 tons burden, with engines of 200 HP., propelled by paddles and heavily rigged. No steamer had then been built for over-sea voyages, but one vessel, the "Savannah," had crossed the Atlantic, in 1819. She had been originally built as a sailing-ship, but was fitted with auxiliary steam-power, the paddle-wheels being designed so that they could be unshipped when the vessel was under sail. She was of very small size (300 tons) and carried only 80 tons of coal. Under steam alone she attained a speed of 6 knots, and on a passage of 35 days, from Savannah to Liverpool, steam-power was only used on 18 days. After this voyage her engines and boilers were removed. This was the condition of things when the founders of this Institution expressed distinctly their appreciation of the importance attaching to improvement in "the art of navigation by artificial power," and in doing so gave proof of their prescience.

Throughout its subsequent history the Institution has continued to manifest keen interest in the construction and propulsion of ships. Its membership has included eminent shipbuilders and marine engineers. The "Proceedings" contain many important Papers dealing with subjects relating to shipping, employed both for commerce and for war. It is therefore the more notable that during the 85 years of its existence no naval architect or shipbuilder has occupied the Presidential Chair. Amongst the Vice-Presidents there have been men eminent in shipbuilding, like Isambard Brunel and Scott Russell, and it would have been most interesting had I been able in this Address to refer to their utterances on a similar occasion. Unfortunately this is impossible; but the fact that I am the first shipbuilder upon whom the honour has been bestowed enhances my appreciation of the distinction conferred by my election as President. I recognize not only the great kindness shown to me individually, but the evidence your choice affords of the high estimate put by this Institution upon the importance of shipbuilding as one of the greatest national industries and as a chief factor in the commerce and defence of the Empire.

May I add a personal acknowledgement of the extreme kindness and consideration shown to me by my colleagues on the Council and by the members generally during the long period of ill-health

through which I have recently passed. My fear has been that the interests of the Institution would suffer from my inability to give that service which every member of the Council ought to render; and I have repeatedly offered to withdraw in order that another and more efficient representative might take office. This suggestion, by your gracious consideration, has not been entertained; and the Institution has secured meantime the services of two distinguished Presidents who, under ordinary circumstances, would have succeeded me. Now that it has happily become possible for me to take this office, I am moved to do my best to serve the Institution not merely by the sense of the high honour of following so many eminent engineers, but by the desire to prove my most grateful appreciation of your unfailing kindness.

It is my purpose in this Address to attempt a review of the progress of shipbuilding and engineering during the forty-four years that have elapsed since I commenced my apprenticeship as a lad of fourteen. The story will deal chiefly with things I have personally seen or known, and it is worth telling; but so wide is the range and so eventful the narrative that it is impossible to do it justice. My endeavour, therefore, will be to indicate the great lines of advance and the principal results achieved, while not leaving altogether unnoticed possibilities of the immediate future.

Before dealing with these questions, however, there are some matters of general interest, although of a "domestic" character, to which brief reference must be made.

Present Position of the Institution.

After eighty-five years of strenuous existence the Institution maintains its vitality unimpaired. The living links with the historic past of civil engineering grow fewer, and the list of surviving Past-Presidents is brief. We shall no more enjoy the genial presence and wise counsel of Edward Woods, whose active career as an engineer began nearly seventy years ago, and whose interest in the work only ceased with his life. We still have with us veterans like Sir Frederick Bramwell and Sir George Bruce, whose example is an inspiration to their younger brethren, and whose interest in the Institution is unabated. Judged by the common standard of the length of its roll, the Institution flourishes. Greater weight attaches, however, to the individual qualification essential to membership than to mere numbers; and, measured by that standard, much progress has been made in recent years. The introduction of a system of qualifying examinations for admission of Students and Associate Members is comparatively

recent. The system has been gradually developed during the last fourteen years, and it has received constant thought and attention from the Council and officers. It is desired that young men entering the profession shall be equipped with a sound general education before they commence their special scientific and practical training. Moreover, the Council insist upon the necessity for practical qualifications as well as for theoretical attainments, the former being proved by a period of actual work under experienced engineers, the latter being tested by examination. Complaints such as were heard during the earlier years of the examinations arose chiefly from the want of due preparation by candidates, and have now almost ceased. Certain difficulties of an administrative nature remain, in regard to the examination of candidates in foreign countries; but these are temporary, as students will more or less realise the necessity for qualifying themselves for admission before going to the colonies or foreign countries.

The general position may be summarized in the statement that by this system the Institution is inculcating, in a Student-Class more than 1,000 strong, the principles it has evolved with regard to engineering training. As our late Hon. Secretary, Dr. Pole, loved to insist, an engineer is "anyone who seeks in his mind, who sets his mental powers in action in order to discover or devise some means of succeeding in a difficult task he may have to perform." The Council is of opinion that to produce such a man practical training and scientific education are both essential. The hall-mark of its membership, under existing conditions, is a proof of competence in both directions. Engineering claims to be one of the learned professions, and we offer the best proof possible in support of the claim. No greater evidence of our interest in the welfare of the students and the future of engineering could have been given than by the establishment of these examinations. The Council call upon all members to continue to do their utmost to attach students to the Institution, and so to make its future more secure.

In the past the Institution stood almost without a rival, dominating the entire field of engineering. As engineering has been developed it has specialized, and societies have been established to deal with particular branches or local needs. The founders of the Institution could not possibly have foreseen subsequent developments, but their scheme was so broadly conceived as to embrace all branches of civil engineering now, no less than it did at the beginning. The Institution welcomes the development of local

and sectional societies, recognizing fully that there is room for them without loss to itself or interference with its work. The co-relation and inter-dependence of all branches of engineering are recognized as being absolutely necessary, and the more so as specialization proceeds. The need for a great Central Institution in which all civil engineers can associate and confer becomes greater, and loyalty to the parent Institution is probably greater now than under earlier and simpler circumstances. We need have no fear for the future so long as the comprehensiveness and catholicity which mark our methods are maintained.

There is one section of the Institution which, to our great regret, has diminished—that of Associates. The advantages to the Institution of maintaining and, if possible, developing this class are unquestioned. There are many distinguished men, other than civil engineers, able to "render assistance in the prosecution of public works," and many others "eminent for science and experience in pursuits connected with the profession of a civil engineer," whose association with our work would be mutually advantageous. It rests with members to make known to such persons the opportunity which our constitution affords for them to become Associates and to enjoy many privileges.

It is possible also that interest in our Proceedings might be enlarged and engineering science advanced by an increase in the number of members contributing Papers. The proceedings of the Conference last June confirmed the impression made by similar meetings in former years. Short papers dealing with specific points of practice or theory give rise to valuable discussions. In the three days of the last Conference 400 speeches were made. Reference to the Proceedings shows that a large number of members have contributed valuable Papers, and that as a rule the discussions thereon have tended to record and disseminate valuable information. Necessarily home members should do most in this direction, and an appeal is made to them to assist in securing the best Papers dealing with subjects of high importance and of immediate interest. Our fellow-members beyond the seas do their part well. Section II. of the Proceedings for the past session contains thirty-one Papers, eighteen of which were contributed by members not resident in the United Kingdom; and seven out of eleven premiums were awarded to them. It is recognized that many members whose work and experience would give special value to their contributions are so fully occupied as to have considerable difficulty in preparing Papers. To them I would venture to say that the briefest notes would be of great interest

and value if circumstances prevent the preparation of more elaborate Papers. The standing of this Institution is such that the honour of contributing to the Proceedings on any branch of engineering should be no less than that which every scientific man feels when a Paper is accepted by the Royal Society.

The question of education and training for engineers is now receiving an unusual amount of attention, for good and sufficient reasons which need not be specified. At the recent Conference a valuable discussion took place, and at other engineering societies similar discussions have occurred. There is undoubtedly a wide-spread feeling that steps should be taken, by competent and representative engineers, to consider whether some common basis for scientific training cannot be arranged by which students could benefit; their specialization in training, for the particular branch to which they would be attached, coming later. It is a hopeful sign that, on the one hand, professors at technical colleges and educational authorities have voluntarily expressed their desire to have advice and guidance in the arrangement of courses of studies; while, on the other hand, leading employers in engineering establishments have declared their readiness to give encouragement and assistance in the practical training of young men who pass through a college course. At present many different systems are in use, admirably summarized by Professor Cormack. Each and all have produced capable men; but clearly the balance of advantage must lie in some system for the average man whose wants should regulate largely the selection made. There is, as I believe, a general and well-founded belief that in this matter other countries have gained upon us by more systematic technical instruction. For thirty years I have given close attention to this subject, and my opinions are definite, but this is not the time to express them. Had it not been for my occupancy of this chair, I should now have been in the United States with the Mosely Commission gaining detailed information. All that I will now say is, that there is undoubtedly a need for inquiry by representative engineers into existing and possible courses of instruction. A request that this Institution should take the lead in constituting a representative Committee to conduct this inquiry is now under consideration by the Council. Upon the decision much depends. But, in any case, there is no danger of interference with the established policy of the Institution in regard to the nature and results of training as above described. Hitherto the Institution has been content to specify essential qualifications in candidates for admission, and to take steps to ascertain whether candidates

possess the specified educational and scientific attainments, together with proper practical training. There is no question raised as to the qualifications: what has to be dealt with is the best method or methods of acquiring the qualifications.

Another matter of great interest at present is the proper organization for the new College of Technology proposed to be established in London. No details of the scheme have been published, and there has been a fear in some quarters that existing institutions might suffer, while over-lapping and waste of money might result. There will be general agreement, I think, that existing means are insufficient, and that they need large extension and supplementing. Further, that it is on all grounds desirable to make full use of existing institutions, adding departments and appliances proved to be necessary. Expenditure on new buildings and laboratories must be carefully scrutinized if the best use is to be made of the money provided by private generosity. It would be deplorable if a false start were made when such a gift has been tendered; for we may hope that there will be many more "pious founders" before long if this undertaking is well organized, and that the reproach of backwardness as compared with the United States will be removed. Sir Arthur Rücker (Principal of the University of London) stated last night that those engaged in framing the scheme are in accord with these guiding principles: and it certainly appears right to reserve judgment until the scheme has been drafted. Equally I would urge that this is pre-eminently a case for conference with the engineering societies, as represented by men eminent in their several departments, before the scheme is settled. It is not to be admitted that men unconnected with engineering and manufactures, however skilled as educationists, can deal with such a matter satisfactorily without the aid of experienced practical men. The model of the Charlottenburg Technical High School is not one to be slavishly copied. Our circumstances and state of advancement are different in many respects. While we can benefit largely by German and American experience, we must have the courage to find our own way: and this can be done if the proper steps are taken in framing the scheme for the new college. Thorough preliminary examination and discussion are essential to success, and deliberate procedure at this stage will be of great ultimate advantage. The co-ordination and extension of technical instruction in London on a scale worthy of the nation is an object we all wish to see realized. It has been brought within the bounds of possibility by the munificence of private

gentlemen, and the support promised by the County Council. I trust that this generous example will be followed by others, and that before this year ends a scheme will be framed that will give general satisfaction.

Benevolent Fund and Yarrow Home.

Whilst separate in organization and management, the Benevolent Fund is so intimately related to the Institution, that an appeal for support to it may be deemed not out of place here. The Fund deals with scores of cases annually, in which timely aid is the means of alleviating the poverty of widows, and assisting the education of orphans, of those who have been unsuccessful in life; as well as cases in which advancing years have found members of the Institution themselves in greatly reduced circumstances. The Fund depends on voluntary contributions; its expenses do not exceed 4 per cent. of its income. If members of the Institution generally realized its work and its liabilities, it would surely receive support from a larger number of them than the 18 per cent. who form the present list of annual subscribers. Were it not for the exceeding liberality of some members, past and present, the Fund would be quite unable to meet the engagements it has undertaken. In this connection it will be of interest to mention what has been for some months past an open secret. Mr. A. F. Yarrow, Member of Council, has generously offered to place under the control of the Council of the Institution the magnificently equipped and endowed Convalescent Home for Children which he has established at Broadstairs, and has carried on with marked success for 7 years. The arrangements for the transfer of such an establishment necessarily involve many important details which are receiving consideration. Our best thanks are due to Mr. Yarrow for this mark of confidence, and for the proposal to place in the hands of the Council this means of ministering to the needs of the children of men in or associated with the engineering profession. It will be of great assistance to the work of the Benevolent Fund.

Visit to America in 1904.

An invitation to visit America was received some months ago from the American Society of Civil Engineers, who wished to return in New York the courtesies it has been the privilege of this Institution to show to American engineers in London on two

recent occasions. Steps were taken by the Council to ascertain the views of members, as such a visit was unprecedented in the history of the Institution, and the replies were of a character which induced the Council to accept the very cordial invitation that had been received. The time will be fixed so as to enable those of the party who desire to do so to take part in the International Engineering Congress which is to be held at St. Louis early in October. Details for the visit have still to be worked out, and this will form one of the occupations of the session.

Engineering Standards Committee.

The work of this Committee proceeds on the lines originally laid down, but extensions of the scheme have naturally taken place, and new Sub-Committees have been appointed to deal with special subjects. Reports have been presented and published dealing with British standard sections for bars of various forms, with tram-rails, and with locomotive-engines for India. It is gratifying to know that, besides the approval and financial assistance of the scheme by the British Government, the India Office has recently made a special grant of £1,000 in recognition of the value of the work done on its behalf. There is reason to hope that, as the scope and character of the undertaking are better understood, and the beneficial results of its operations made apparent, more adequate assistance from the public funds will be available, as the efficiency and commercial success of so many branches of manufacture must be greatly promoted. Members of the Committee are giving gratuitous service to the State to an extent representing very large contributions from the engineering profession.

While my sympathy with the work of standardizing is thorough, and I have adopted it for 25 years in my own practice, I cannot leave the subject without recording the opinion that there is a danger of unwise advocacy and undue extension of such methods. Some advocates of standardizing—not engineers—are so enamoured with the idea of advantage resulting from repetition of patterns and identity of forms, that they are often in danger of pushing the process to absurd and injurious lengths. Interchangeability is desirable within limits, and so long as it is practically effective; but when it has little or no practical value in service, and involves greatly increased first cost and delays in manufacture, then standardization is not to be commended. Nor should it be ever

permitted to kill down continuous improvement, paralyse invention, or prevent completion in design tending to advance. These may seem truisms, but the caution is not given without adequate reason. So long as standardization remains in the hands and under the control of such a representative committee of practical engineers and manufacturers, the dangers mentioned need not be feared. It is the amateur who, in concentrating attention on one aspect of a great subject, loses sight of others and retains no sense of proportion, who is to be feared, when he has the power to influence action.

The State of Shipbuilding up to 1859.

Turning to the main subject of this Address—progress in shipbuilding and marine engineering since 1859—it is desirable to state briefly what was the position of affairs at the initial date, and how it had been reached.

The art of shipbuilding is of great antiquity. For many centuries it was extremely slow. The ancient boats discovered in Egypt display features of form and structure remarkable even now, and so do the Vikings' ships of Scandinavia. Until the close of the Eighteenth Century the hulls of all ships were wood-built, and although iron began to be used for sea-going ships nearly seventy years ago, wood continued to be more largely used than iron up to 1868. Sails were the only means of propulsion for sea-going ships—except in small vessels where oars could be used—until the accession of Queen Victoria; although (as already indicated) steam was applied to the propulsion of vessels employed on rivers, canals, coasting and cross-channel services, during a quarter of a century previously. Improvements were made, it is true, in structures, types and sail-equipment as centuries passed, but they were slow and very gradual. The sizes of ships were moderately increased. Radical changes were very rare; no great steps in advance took place.

In 1514 the finest specimen of British shipbuilding was the "Henry Grace à Dieu." Her exact dimensions are doubtful, but it is probable that she was 138 feet long, 38 feet broad, and of 1,000 tons burden. Details of her armament are recorded: it included 120 guns, most of which were very small; there were four 60-pounders, three 33-pounders, and four 17-pounders. Her cost was about £8,700. A century later was the "Prince Royal," 140 feet long, breadth 44 feet, burden 1,200 tons to 1,400 tons, and cost £20,000. She carried fifty-five guns, the heaviest projectile weighing

33 lbs. In 1670 the "Sovereign of the Seas," 168 feet long, 48·3 feet broad, 1,640 tons burden, carried 100 guns, the heaviest projectile weighing 60 lbs. This was a design severely criticised by naval experts of the period. The masters of Trinity House declared that the construction of a three-decker was "beyond the art or wit of man," and that there was no port, "the Isle of Wight only" excepted, in which she could ride, and no ground-tackle which would hold her. These prophecies were falsified. Phineas Pett, who designed her, was exceptional in being a Cambridge graduate as well as a shipbuilder, and obviously understood his business. He estimated the cost at £13,680; unfortunately the actual cost approached £41,000, representing probably over £300,000 at present values. There is no record of any investigation of the discrepancy between estimate and expenditure, but Pett connected it with "certain extraordinary charges of new building of dwelling-houses in Woolwich Yard," which he "doubted not were brought upon the charge of the ship." There seems to have been no Auditor-General in those early days.

Nelson's flag-ship at Trafalgar, the "Victory," still lying in Portsmouth Harbour (with some of the original structure remaining, no doubt) was built in 1765. She was 186 feet long, 52·3 feet broad, of 2,164 tons burden, first cost about £70,000, carrying 100 guns on three decks; the heaviest projectile weighed 56 lbs. The sailing three-deckers of 1839 were 204 feet long, 60 feet broad, of 3,100 tons burden, carrying 110 guns; the heaviest projectile weighed 56 lbs. The cost was between £110,000 and £120,000. Here we have a summary of progress in warships made during three centuries, and it justifies the foregoing statement of slow progress and lack of radical change. Some of these sailing line-of-battle ships remained in commission up to 1859, and I have seen them in Plymouth Sound.

Merchant-ships were of much smaller size than warships, and not equal to them in structure or sail-equipment. Relatively they had gone back since the Elizabethan age, when "adventurers," or armed merchant-ships, were fit associates or rivals for regular men-of-war. A vicious Tonnage Law had hampered design and prejudiced sea-going qualities, while the stress of foreign competition was not much felt during the earlier portion of the Nineteenth Century, and British merchant shipping held a preponderating position in the trade of the world.

The period 1840–60 was marked by the gradual development of iron-shipbuilding and screw-propulsion. As was natural after centuries of stagnation, there was strong and persistent opposition

to departure from long-established custom, especially in war-fleets. The pioneers in these advances had an arduous task, and the world owes much to their courage. Amongst them may be mentioned Fairbairn, Laird, Grantham, Scott Russell and I. K. Brunel—the last-named doing by far the greatest work. To him was largely due the adoption of the screw-propeller for sea-going ships, both in the Royal Navy and in the mercantile marine, the practical demonstration of the possibility of ocean steam-navigation over long distances in the "Great Western" (1836), as well as the potentialities of iron as a material for constructing ships of large size, first in the "Great Britain" (1843) and subsequently in the "Great Eastern" (1853). It is interesting still to read his account of difficulties at the Admiralty in relation to the introduction of the screw-propeller into warships, and of his interviews with naval lords. The Surveyor of the Navy at that time, who was responsible for the design of ships, and the principal technical adviser of the Board on questions of ship-design, was a naval officer; an amateur designer, not an educated naval architect. He had held office since 1832, and was strongly opposed to the introduction of steamships, nor did he stand alone in that opinion. On his retirement in 1847 another naval officer was appointed to the post, eminent as a practical seaman, but not trained as a naval architect. He was not held responsible for the designs of ships, competent naval architects being associated with him who had been educated in the first English School of Naval Architecture. No real change of system followed for some years. Mr. Andrew Murray (writing in 1863) said of this period: "Naval members of the Board of Admiralty were men who had long looked upon the noble line of battleships of the Navy as not to be surpassed, and they could not apparently make up their minds to desecrate them, as they seemed to consider it, by the introduction of steam-power. The result of this somewhat romantic feeling was that a number of sailing three-deckers were laid down in opposition to the expressed opinion of the leading civil professional officers attached to the Admiralty. Not one of these vessels, as had been predicted, was launched as a sailing-vessel. They were converted into screw-ships by being lengthened amidships, at the bows, and also at the sterns." Until 1852 no two-decker was designed for a screw-propeller, although the superiority of the screw over the paddle had been conclusively proved by Brunel's experiments made in 1843, and by the performances of the "Great Britain."

As regards the use of iron for the hulls of warships there was perhaps more reason for hesitation, even after the enormous

advantages of the material were demonstrated by the behaviour of the "Great Britain" when ashore in Dundrum Bay (1846). Two light iron steamers built for the East India Company were successfully employed in the war with China (1842), and a few years later several iron screw-frigates were ordered for the Royal Navy; but after a long series of experiments with targets representing the sides of these vessels, it was decided to turn them into transports. This decision appears to have been based upon the greater "splintering" of the iron sides when struck by solid and hollow spherical shot, as compared with wood sides. On the other hand, it was found that iron plating exceeding ½ inch in thickness broke up shell from the heaviest guns then afloat. This undoubted advantage was not considered to counterbalance the "splintering"; and the greater danger of wood ships taking fire, when attacked by shells, was not duly estimated. So wood remained in possession as the material for hulls of warships up to 1859. The question of adequate supplies of suitable timber had become acute long before this. Purveyors were searching far and wide in foreign countries, as well as at home, and anxious questionings arose as to the provision of stocks for use in case of war. Foreign countries with home-grown timber in abundance had an enormous advantage. The outlook was serious.

In the mercantile marine much greater progress was made in the use of iron, but wood died hard. So late as 1860 two-thirds of the tonnage added to the British register was wood-built. Steam-power was being extensively adopted, but sail still held predominance. Out of 262,000 tons of merchant shipping added in 1860, over 168,000 tons were in sailing-vessels. Paddle-wheels were much more extensively used than screws, but the latter were gaining favour for ocean-going steamships. So late as 1862 the Cunard Company built the iron paddle-wheel steamer "Scotia," of nearly 3,900 tons (gross) and 4,200 horse-power.

Paddle-wheels in warships were much more exposed and liable to damage in action than well-immersed screw-propellers: consequently in the larger frigates and the line-of-battle ships, when steam-power was introduced, screws were adopted. The Navy List of 1859 contained 413 ships, from three-deckers down to sloops. Line-of-battle ships numbered 110, of which 46 were sailing-vessels; frigates 124, of which 82 were sailing-vessels. All the steam battleships and frigates had screws. Of the smaller classes 50 were screw-steamers, 64 paddle-steamers, and 65 sailing-vessels. Less than 1 per cent. of the total tonnage was iron-built.

All classes of sea-going steamers for war and commerce were then

furnished with full sail-equipment in order to economize coal and to provide for possible breakdown of machinery. Steam-power was regarded as auxiliary to sails.

The United States, thanks to their great supplies of timber and the skill of their shipbuilders, were becoming dangerous competitors. In 1859 they built 156,600 tons as against our 213,000 tons; in 1860, 214,800 tons against our 225,900; and in 1861, 233,200 tons against our 208,000. We had lost the lead temporarily when the Civil War broke out.

In 1850 the United Kingdom owned 3,565,000 tons of shipping, and British possessions nearly 668,000 tons, while the United States owned 1,586,000 tons of vessels in over-sea trade, and 1,900,000 tons in home trade, including lakes and rivers. Ten years later the figures were: United Kingdom 4,659,000 tons, British possessions 1,052,000 tons, United States 2,546,000 tons for over-sea trade and 2,753,000 tons for home trade. There had consequently been a sensible gain on us in the period.

While our position as the leading shipowning and shipbuilding country was thus threatened, fresh anxiety was created as to our naval supremacy by the new departure made in France, under the personal inspiration of Napoleon III. and the skilful technical work of the great naval architect, Dupuy de Lôme, in the construction of sea-going ironclads. As long ago as 1824 another Frenchman, General Paixhans, had introduced horizontal-firing shell-guns, and pointed out the enormous dangers to wood-built ships when subjected to these attacks, not merely from injuries to structure, armament and crews, but from conflagration. He proposed to coat the sides of ships with iron plates as a defence, but nothing practical resulted from his or similar suggestions until the Crimean War. The destruction of the Turkish fleet at Sinope in 1854 emphasized his argument, and the French immediately undertook the construction of floating batteries specially designed for the attack of Russian land-fortifications. The Admiralty followed this lead. They were really floating forts, with 4-inch to 4½-inch solid iron plates on their sides, extending from stem to stern and from the upper deck down to a few feet below water. Within this battery were mounted a number of the most powerful guns then available. Some of them actually took part in bombardments, and their defence proved capable of keeping out not merely concussion-shells but solid shot from the heaviest guns in existence. This result, when compared with the serious damage sustained by unarmoured ships in the attacks on Sebastopol and other Russian fortresses, naturally led to the proposal to extend armour-

plating to sea-going ships; in France action was not long delayed. Before the close of 1857 Dupuy de Lôme had matured his designs; in May, 1858, two ironclads were on the stocks, and before the close of that year a third was begun. Mr. Dupuy showed caution as well as courage in his procedure. He adhered closely to the forms, dimensions, engine-power and speed of successful two-deck screw line-of-battle ships, but reduced the height above water; having only one tier, and a considerably less number of guns, as well as a somewhat greater length of ship. The weight thus saved was appropriated to iron armour arranged much as in the floating batteries, and about 4½ inches thick. Naval opinion at the time was distinctly adverse to these changes, especially in this country. It was held that ships burdened with great weights of armour would prove ill-behaved, if not dangerous, at sea. The naval officer who then held the post of Surveyor of the Navy made no secret of his ignorance of the principles of naval architecture, and is said to have laid it down that in his opinion this country ought not "to take the lead in naval improvement, but only to follow on a larger scale the improvements of others." The naval architects serving under him had no such encouragement as was enjoyed by Mr. Dupuy, and private shipbuilders were left without opportunities of showing what could be done in this country. Mr. Scott Russell, for example, submitted to the Admiralty a design for a sea-going ironclad three years before "La Gloire" was laid down: but no use was made of it. Other private firms were equally ready to furnish designs, and no opening was given. Public feeling was naturally aroused, and controversy was keen. But the Admiralty took no action to meet the French menace by beginning ironclads; and so late as 1859 all our exertions were devoted to hastening the steam-reconstruction, converting into steamers, at great cost, ships that should never have been built as sailing-vessels, and commencing screw-steamers of improved form and speed but with unarmoured wood hulls. In 1859–60 no less than seventeen line-of-battle ships and ten frigates were converted or launched as screw steamers; and at the close of the year 1860 twelve line-of-battle ships and thirteen frigates remained unfinished. By that date the French had ten ironclads building; and before the year 1860 ended two or three were ready for sea. This was done while the pressure of the Italian war was at its greatest. Here, with uninterrupted peace, nothing was done until May, 1859, when our first sea-going ironclad, the "Warrior," was ordered. This decisive step is said to have been taken mainly on the decision of the then First Lord (Sir John Pakington, afterwards

Lord Hampton), and against the advice of many naval officers of high rank. A change of Ministry followed in June; and the Duke of Somerset, before the year ended, ordered a sister-ship to the "Warrior," as well as two smaller ironclads. Thus, after long delays the ironclad reconstruction of the Royal Navy at length began, no one then foreseeing the enormous changes which were to follow in the structures, types, protection-armament, speeds and coal-endurance of warships during the next half-century. Strange to say, in a new classification of ships authorized by the Admiralty in January, 1860, no place seems to have been assigned to these ironclads amongst the battleships. First-rates were to carry 110 guns and upwards, second-rates 80 to 109 guns, and third-rates 60 to 79 guns. The "Warrior" was to carry 40 guns, and her "rate" was undetermined.

Shipbuilding in 1859–60.

In March 1859, before the "Warrior" was ordered, my association with shipbuilding began. The Royal dockyards were then crowded with men, working overtime to hasten the steam-reconstruction. My first employment was on a line-of-battle ship, built as a sailing three-decker many years before, which was undergoing conversion into a screw two-decker. During the year I assisted at the "lengthening" of a sailing-frigate which was cut into three pieces, the bow and stern portions being drawn apart, and the form modified to receive a screw. I also witnessed the commencement of new line-of-battle ships and frigates, which were pushed forward rapidly for a time, then left on the stocks for years, and finally taken to pieces. A more singular illustration of indecision and unproductive expenditure it would be difficult to discover.

The screw three-deckers built in 1855–59 were splendid specimens of what could be accomplished with wood as the principal material for construction, and embodied not merely the accumulated experience of centuries in hulls, rigging, equipment and armament, but that of nearly half a century of marine engineering. The "Victoria," launched in November 1859, was 260 feet long, 60 feet broad, had a mean draught of 26 feet 3 inches, and an extreme draught of nearly 28 feet. Her displacement was about 7,000 tons, her engines developed 4,200 HP., with a corresponding speed of about 12½ knots. She had a full sailing-equipment, the sails aggregating 31,000 square feet in area. The funnel could be lowered, and the screw could be lifted out of water when the ship

was under sail. Her armament consisted of 121 guns, mounted on three gun-decks and an upper deck. All were smooth-bores, firing spherical cast-iron projectiles; one was an 8-inch 68-pounder pivot-gun, weighing 95 cwt., 62 were 8-inch shell-guns, weighing 65 cwt. and firing 56-pound projectiles, and 58 were 32-pounders weighing 56 cwt. All except the pivot-gun were mounted on wooden-truck carriages. How small had been the advance in naval gunnery will be seen from the statement that in the ships of Queen Elizabeth's reign there were guns of 8 inches to 8½ inches calibre, discharging projectiles weighing 60 lbs. to 66 lbs. There were, of course, many features in the later weapons giving them superiority over the earlier, and the 8-inch shell-gun indicated a new departure. But in essentials of guns, mountings and projectiles, there had been no great change in nearly 300 years. The cost of the "Victoria" was £217,000, nearly one-third of that amount being expended on machinery.

It will be interesting to add a few facts as to the largest representative merchant-ships of 1859–60. With the advent of iron hulls and steam-power came rapid growth in dimensions of merchant-vessels, but they were still inferior to the largest war-ships in displacement.

The finest ship in the Cunard fleet in 1859 was the iron paddle-wheel steamer "Persia." By the courtesy of the Company I have been able to add to the particulars of this notable vessel which have appeared in various publications. She was 360 feet long, 45 feet broad, and 31·5 feet in moulded depth. Her gross register tonnage was 3,300 tons. Her deep load-draught leaving port was about 23 feet, with a corresponding displacement of about 6,000 tons; if laden to 24 feet it would have been about 6,400 tons. Her engines developed 4,000 HP., and gave her a sea-speed of nearly 13 knots; the daily consumption of coal was 150 tons, and she carried 1,600 tons in her bunkers. Her dead-weight capacity for cargo was 1,100 tons, and she had cabin-accommodation for 180 passengers. This was the finest Trans-Atlantic steamer of that date. Her fastest passages took 9 days to 10 days. She was heavily rigged, and the quicker passages were, no doubt, made with favourable winds.

The iron screw-steamer "Ceylon," of the Peninsular and Oriental Company, was in 1859 the finest vessel on the Alexandria mail-service; she was 306 feet long, 41 feet broad, and nearly 28 feet deep; 2,000 tons gross register tonnage; load-draught about 20 feet; corresponding displacement about 3,700 tons. Her engines developed about 1,500 HP., and her sea-speed was 12½ knots to 13 knots; she burnt about 60 tons of coal per day, and carried

11 days' to 12 days' supply. In 1859 two other steamers were built, of less tonnage, and in 1861 the "Mooltan" was added to the fleet, having 2,260 tons gross tonnage, a length of 350 feet, 1,740 HP., and 12 knots sea-speed. A still earlier vessel built for this famous line, but bought for the Admiralty transport service, was the "Himalaya," which was described in 1853 as "of larger dimensions than any (steamer) afloat, and of extraordinary speed." She was 340 feet long, over 4,000 tons displacement, 3,400 tons gross tonnage, 2,000 HP., and 12 knots speed.

Turning to the Cape Service, in 1860 the mails were carried in iron screw-steamers about 180 feet in length, 25 feet broad, and 17 feet deep, having a mean draught of 14 feet, with a displacement of about 1,100 to 1,200 tons. The gross tonnage was 550 tons, horse-power about 300 to 350, speed 8½ knots to 9 knots. In 1863 two new iron screw-steamers were built, having a speed of 11 knots and engines of 750 HP. to 800 HP. The "Roman" was nearly 270 feet long, 32·4 feet broad, and 23·6 feet deep, of 1,280 tons gross, drawing 18 feet of water. Both ships carried 700 tons of coal in their bunkers, and were estimated to burn about 17 tons a day.

The Royal Mail Company were carrying mails and passengers to the West Indies in vessels of 12½ knots to 13½ knots sea-speed. The "Atrato" was their largest vessel in 1860. She was 336 feet long, 41 feet broad, and 33·7 feet deep, over 3,100 tons gross, drew about 21 feet when laden, was propelled by paddle-wheels driven by engines of 2,500 HP. to 3,000 HP., and had a speed of 13 knots to 13½ knots.

The Great Eastern (1853–90).

These particulars for representative steamships are of interest as illustrations of the progress made from the real commencement of ocean steam-navigation in 1838, and as a means of comparison between the largest and swiftest mail-steamers of 1859–60, and the largest screw line-of-battle ships of that date. In addition they are of value as an indication of the magnitude of the departure from precedent and experience made by Brunel when he undertook the design of the "Great Eastern." That wonderful ship started on her first cruise on 7 September, 1859, and the great engineer died on 19 September. Fortunately there remains in the Reports and Memoranda included in his published "Life," a fairly complete account of the fundamental ideas on which the design of the vessel was based, the manner in which the dimensions were determined, and the structural features decided. Brunel, to

quote his own words, was convinced that "to make long voyages economically and speedily by steam, required the vessels to be large enough to carry coal for the entire voyage, at least outwards; and unless the facility for obtaining coal was very great at the outport, then for the return voyage also; and that vessels much larger than had been previously built could be navigated with great advantage from the mere effect of size." At the close of the year 1851 he began to study the problem of constructing a vessel capable of carrying coal sufficient for the voyage to Australia and back—that is, the circumnavigation of the world—in association with the accommodation for a large number of passengers and a reasonable amount of cargo. This subject occupied no small share of his time and thought until the end of 1853, when contracts were signed for the construction of the ship and propelling-machinery. Brunel sought advice and assistance in all quarters, and frankly acknowledged his obligations, saying to the directors of the company formed to build the ship, "I have not hesitated to consult everybody whose opinions I considered valuable, and to bring the result of their opinions in aid of my own and the manufacturers' experience." But it is clear that all the great features of the design—structure, arrangement of propelling-machinery and determination of dimensions—were his own work. He accepted full responsibility and spared no pains to secure success. He said:—"I never embarked on any one thing to which I have so entirely devoted myself, and to which I have devoted so much time, thought and labour, on the success of which I have staked so much reputation, and to which I have so largely committed myself and those who were disposed to place faith in me." There is ample evidence that this was no exaggerated view of his action. Personally I have been familiar with the facts for many years, but having recently gone again most carefully through Brunel's notes and reports, my admiration for the remarkable grasp and foresight therein displayed has been greatly increased. In regard to the provision of ample structural strength with a minimum of weight, the increase of safety by watertight subdivision and cellular double bottom, the design of propelling-machinery and boilers, with a view to economy of coal and great endurance for long-distance steaming, the selection of forms and dimensions likely to minimize resistance and favour good behaviour at sea, and to other features of the design which need not be specified, Brunel displayed a knowledge of principles such as no other ship-designer of that time seems to have possessed; and in most of these features his intentions were realized. To him large dimensions caused no fear. "The use of iron," he

remarks, "removes all difficulty in the construction, and experience of several years has proved that size in a ship is an element of speed, strength and safety, and of greater relative economy, instead of a disadvantage; and that it is limited only by the extent of demand for freight, and by the circumstances of the ports to be frequented." He looked at the matter as an engineer rather than as a commercial man; but there were merchants and financiers who were convinced that on the trade routes, *viâ* the Cape of Good Hope, to India and Australia, there was scope for the employment of great ships at remunerative rates, carrying cargo and passengers at high speeds. The capital was raised, and in the spring of 1854 the construction of the "Great Eastern" began. After many vicissitudes she was launched on 31 January, 1858, and made her first cruise in September, 1859.

Exception may reasonably be taken now to the wisdom of the fundamental conditions laid down for the design, or to the correctness of the estimates of possible earnings. From the technical side, however, interest centres in the fact that Brunel undertook to produce a ship capable of carrying coal sufficient for the voyage to Australia and back, at an average speed of 14 knots, 36 days being allowed for the passage. She was to accommodate 3,000 persons easily, to carry a small amount of cargo only on the outward passage, and homeward to bring "any amount that could be collected," cargo taking the place of the coal burnt on the voyage out. The great ship was to be equally available for service between England and India if required, carrying coal enough to take her to Calcutta and thence to Trincomalee with 3,000 tons of cargo.

The dimensions ultimately adopted were: Length over all, 693 feet; between perpendiculars, 680 feet; extreme breadth of hull, 83 feet; over paddle-boxes, 120 feet; depth, 58 feet. Like all the passenger-steamers of that period she had very small erections above the upper deck, and while her gross tonnage was 18,915 tons, her "under-deck" tonnage was 18,837 tons. It was proposed that, as a rule, the draught of water should not exceed 30 feet, corresponding to a displacement of 27,400 tons; but she was capable of being laden more deeply if required. Brunel discussed the case of 32 feet draught, corresponding to about 30,000 tons displacement; and in 1870, when cable-laying, she drew about 34½ feet to 35 feet, with a displacement of 32,700 tons. In order to maintain the average sea-speed of 14 knots, it was estimated that 7,000 HP. to 8,000 HP. must be continuously developed. mple boiler-power was provided and arrangements made by

which for short periods the power developed could be increased to 10,000 HP. or 11,000 HP. At the time of the design (1852–3) it must be remembered that the most powerful Cunard steamers were 285 feet long, of less than 2,500 tons gross and 5,000 tons displacement at deep draught, having 12½ knots sea-speed, the engines developing 3,000 HP.; while the "Himalaya," as previously mentioned, was 340 feet long, 3,400 tons gross, 4,000 tons displacement, with 2,000 HP. and 12 knots speed. The screw two-deck line-of-battle ship "Agamemnon" of the same date was 230 feet long, of 5,000 tons displacement, and on the measured mile attained 11¼ knots with 2,300 HP.

Under these circumstances it was necessary to subdivide the power; so that the step required of the manufacturers, beyond previous experience, should be minimized. Brunel decided to associate paddle-wheels with a screw-propeller, and to have about 60 per cent. of the total power in the screw-engines. Mr. Scott Russell undertook the construction of the paddle-engines, and of the hull, while Messrs. Boulton and Watt made the screw-engines. In both cases the task was efficiently performed, and the engines did well throughout the service of the ship.

Brunel thoroughly appreciated the paramount importance of economy in coal-consumption on a voyage of such great length. He insisted on 25 lbs. pressure per square inch, although leading marine engineers urged him not to go beyond 15 lbs.; he proposed steam-jacketing (with steam supplied from an auxiliary boiler of higher pressure than the main boilers), superheating and improved jet-condensers, besides other devices for preventing waste of heat. On these heads his notes are of the greatest interest. His estimate was, that a consumption of 200 tons per day would suffice at 14 knots. Taking 7,000 HP. only as the power developed, this means that the rate of coal-consumption he anticipated would have been 2¾ lbs. per indicator horse-power-hour. The best practice at that time gave 3½ lbs. to 4 lbs. per horse-power-hour; and, although many of Brunel's ideas were not carried out in the construction, it is obvious that in this important particular he was much too sanguine. Records of actual consumption are few and somewhat conflicting, but a careful analysis of the figures leads me to the conclusion that at 14 knots the vessel must have burnt at least 350 tons per day, and probably burnt 380 tons to 400 tons per day.

She was never tried on the Australian service, and on the Atlantic her voyages were so few, irregular and marred by accidents, that there was no true test of her capability, nor was she

run at the deep departure-draught of 30 feet. She attained average speeds of 13 knots to 14 knots, and daily runs at 14½ knots to 15 knots. Probably the latter were made with sail set and a favourable wind, for the "Great Eastern" was fitted with six masts, three being square-rigged and three fore-and-aft, with a total sail-area of about 40,000 square feet. With five funnels in addition and great height of freeboard her appearance was imposing.

With her duplicated machinery the risk of breakdown was, of course, diminished, and auxiliary sail became of less importance. Manœuvring power was also greatly increased by this duplication and the power of disconnecting the paddle-wheel engines. The large coal-supply required under the conditions of the design, and the great cargo-capacity, necessarily involved considerable variations in draught of water, and thus affected the efficiency of the paddle-wheels. At 30 feet draught it appears that an immersion of the floats of 15 feet was contemplated, the diameter of the wheels being nearly 57 feet. Had Brunel's estimate of coal-consumption been realized, the ship would have lightened about 6 feet on the passage to Australia by consumption of coal alone, apart from the use of water-ballast; if she had started, as Brunel contemplated, at 32 feet draught, the immersion of the floats would have varied between 17 feet and 11 feet. With the actual rate of coal-consumption, say, 75 per cent. above his estimate, the variation would have been between 17 feet and 6½ feet immersion. The double bottom could be used for water-ballast, and 2,500 tons could be admitted if desired. On the Atlantic service the voyage was only one-fourth as long, and the corresponding variations in draught less considerable.

The screw-propeller was 24 feet in diameter, and therefore fairly well immersed. Brunel carefully studied its design, and had the advantage of unusual experience with screw steamships from the "Archimedes'" trials in 1840 onwards. His remarks, written in 1855, might be repeated to-day with little variation:—

"I have always found the reports made upon the results of various forms of screws and propellers, and the performance of different vessels so little to be depended upon, even when apparently made in good faith, and the results obtained from good authority, that I have been long since compelled to adopt no conclusion unless from results witnessed by myself or by persons observing for me."

It has surprised me to find no trace in Brunel's notes of any contemplated use of twin-screws instead of a combination of screw

and paddles. He left so few stones unturned in his search for the best, that it is singular to find this arrangement unnoticed. There had been many proposals for twin-screws, and I have myself seen, many years ago, a design prepared about 1840 by Nasmyth, of steam-hammer fame, for a twin-screw ram with inverted vertical cylinder engines. Moreover, in 1852, Mr. Roberts proposed an arrangement for applying independent engines to each shaft of twin-screw ships of large size; while Mr. George Rennie built and experimented with a twin-screw launch, which was so successful that many others followed. Subsequent experience has shown that had twin-screws been fitted, substantial improvement upon the results obtained in the "Great Eastern" would have been secured, and the great variations in draught of water would have had much less effect upon propulsive efficiency, while the weights of machinery would have been reduced, and the serious inconvenience of an increased breadth of 37 feet over the paddle-boxes avoided.

In deciding upon the form and dimensions of the vessel, Brunel took counsel with Scott Russell, and could have found no more competent adviser. Writing in 1857, Scott Russell defined his position thus: "I designed her lines and constructed the iron hull of the ship, and am responsible for her merits and defects as a piece of naval architecture. Her lines are identical with those of my other ships, which are constructed like this on a principle of my own, which I have systematically carried out during the last twenty years, and which is commonly called the wave principle." It is obvious also from Brunel's notes that the estimates for engine-power to attain the desired speed were made in conference with Scott Russell. But it is no less obvious that Brunel had his own original views on form and proportions, insisting that "positive length independently of relative length" (*i.e.* ratio of length to beam) has much to do with resistance and behaviour. He also urged the advantages to be obtained by "continuing a gentle curvature throughout the length instead of having any parallel lines" amidships, and cautioned Scott Russell "to be careful not to sacrifice much to keep a small beam." This was at a time when the accepted view of water-resistance to a ship in motion made it proportional to the area of immersed midship section, and therefore favoured narrowness. It may be interesting to state that, having carefully looked into the matter in the light of present knowledge, I am of opinion that the estimate of power required to drive the "Great Eastern" at 14 knots, with an average draught of about 25 feet, is practically identical with that which would now be made for the ship if propelled by twin-

screws. Taking into account the enormous size of the ship in comparison with any other steamer when she was designed, this is a very remarkable result.

In structure the "Great Eastern" was not merely a marvel considering the date of her construction, but is still, in my judgment, a most fruitful and suggestive field of study. Here Brunel was greatly influenced by practice in bridge-building. To him a ship had always been a girder, in regard to longitudinal strength, from the time (1836) when he designed the "Great Western." In the "Great Britain" (1839) he made many new structural arrangements which proved most successful; and that ship did good service for nearly forty years as a steamer before she was converted into a sailing-ship, and subsequently into a hulk in the Falkland Islands. When he began work on the "Great Eastern," he laid down the "principle of construction" that "no materials shall be employed on any part except at the place and in the direction and in the proportion in which it is required, and can be usefully employed for the strength of the ship, and none merely for the purpose of facilitating the framing and first construction." His view, with which I heartily concur, was that in order to minimize weight in the structure, and to increase carrying-power, it is, as a rule, worth while to incur some extra first cost in construction. In his opinion, the expenditure of large proportionate weight in numerous closely-spaced transverse ribs or frames—almost a necessity in wooden ships—was wasteful in an iron ship. "All this misconstruction," he said, "I forbid, and the consequence is that every part has to be considered and designed as if an iron ship had never before been built; indeed I believe that we should get on much quicker if we had no previous habits or prejudices on the subject." Habit and prejudice are still maintaining many arrangements similar to those which Brunel condemned.

The Menai tubular bridge undoubtedly influenced Brunel greatly in the main features of the structure of the "Great Eastern," and the experiments made by Robert Stephenson and Fairbairn furnished valuable information. The vessel was constructed with a cellular upper deck and double bottom, the latter rising about 34 feet above the keel, at which height a strong iron deck (the lower deck) was constructed. The cellular upper deck was 58 feet above the keel, and between it and the lower deck two other comparatively light decks were built, serving as platforms for the cabins. For 350 feet of the length amidships, in the space occupied by engines, boilers and bunkers, two strong longitudinal bulkheads extended from the cellular double bottom to the

upper deck. The main frames in the double bottom were longitudinal, spaced about 30 inches apart below the bilges and 5 feet apart above them. Similar longitudinals stiffened the cellular upper deck. In this manner the necessary longitudinal strength was provided. Transverse bulkheads, spaced about 60 feet apart, with partial bulkheads placed about 20 feet apart, supplied the necessary transverse strength; the upper and lower decks, and cellular double bottom, distributing their strength over intermediate portions of the structure. There were no closely-spaced ribs of the ordinary kind. By the watertight bulkheads and longitudinal frames the cellular double bottom was divided into fifty watertight compartments, thus adding greatly to the safety in case of grounding. The hold space was also minutely subdivided by the bulkheads just described. Indeed, in regard to subdivision the "Great Eastern" compared favourably with any ship of her time, and is in advance of most existing ships.

As to strength, the vessel was severely tested during the thirty-two years she remained afloat. She carried enormous loads of submarine cables, encountered very severe weather, ran on the rocks off Montauk Point, and tore a hole in the outer skin 80 feet long by 10 feet broad, but proceeded to New York, her passengers being unaware of the damage done. She was repeatedly beached on a "gridiron" on the Mersey and at Milford Haven for repairs; yet throughout this service no signs whatever of structural weakness occurred and local damage was readily made good.

I have most thoroughly investigated the question of the weight absorbed in the structure of the "Great Eastern," and my conclusion is that it is considerably less than that of steel-built ships of approximately the same dimensions and of the most recent construction. Of course these vessels are much faster, have more powerful engines, and have superstructures for passenger accommodation towering above the true upper decks which form the upper flanges of the girders. These, and other features I cannot now specify, involve much additional weight: and the "Great Eastern" has the advantage of being deeper in relation to her length than the modern ships. After making full allowance for these differences, my conclusion is that the "Great Eastern" was a relatively lighter structure, although at the time she was built only iron plates of very moderate size were available. The plates used for the outer and inner skins were only $\frac{3}{4}$ inch thick, notwithstanding the exceptionally deep draught and large areas of unsupported bottom plating: they were only 10 feet long and 33 inches wide. The double bottom was 34 inches deep—sufficient for accessibility and

painting, but no more. The weight of a single plate was less than 7½ cwt.: nothing above double riveting was found necessary, including butts. The iron used is not likely to have had an ultimate tensile strength exceeding 20 tons per square inch. The contrast with modern conditions is great. In the "Oceanic," for example, Messrs. Harland and Wolff used steel plates 28 feet long and 4½ feet wide, with thicknesses varying between 1 inch and 1⅜ inch, weighing 2 tons to 3¼ tons, the ultimate tensile strength being 30 tons to 32 tons per square inch. On the side of materials Brunel was at a great disadvantage: he would have rejoiced in the qualities of mild steel, and the developments in manufacture of plates and bars.

This record of achievement in the "Great Eastern" seems only just, as the commercial failure has somewhat obscured the merit of the design. Never employed on the service for which she was built, and unfortunate as a passenger-steamer, the great ship found useful employment in laying cables from 1865 to 1875. Then came a period of fresh difficulty. In 1884–5 it was proposed to use her as a coal hulk at Gibraltar. Afterwards she was used as a floating place of entertainment—an ignoble service. When last I saw her, in 1890, she was being broken up, having been sold for £16,000.

Mr. Henry Brunel, whose recent death we deplore, has often expressed to me the wish that the "Great Eastern" could have been purchased and preserved as a memorial of the greatest feat in shipbuilding ever accomplished. Apart from his filial reverence for a distinguished father, much could be said in favour of the proposal. Now that the ship can no longer be inspected, her exceptional qualities ought not to be forgotten.

Writing in 1876, Lindsay (in the "History of Merchant Shipping") said:—"It may be, a hundred or fifty years hence, the maritime commerce of the world may have grown to an extent sufficient to justify, with reasonable prospects of profit, another ship of the dimensions of the "Great Eastern." Little more than 20 years elapsed before the White Star "Oceanic" was designed, to be soon followed by the German "Kaiser William II." and the "Cedric," all closely approximating to the "Great Eastern" in dimensions and displacement but exceeding her in tonnage: now Messrs. Harland and Wolff have in hand the "Baltic," nearly 30 feet longer, 4,400 tons greater displacement, and 3,400 tons gross tonnage more than Brunel's masterpiece in shipbuilding, while still larger ships are contemplated for the Atlantic passenger-service.

THE FIRST BRITISH SEA-GOING IRONCLAD, "WARRIOR."

The design of our first sea-going ironclad, the "Warrior," was greatly influenced by Scott Russell, who had built the "Great Eastern." Competitive designs had been invited by the Admiralty from leading private firms, and the Royal dockyards. None of these was adopted, the Admiralty naturally having views of their own; and the design finally approved was prepared in the Constructive Department. Scott Russell always spoke of the "Warrior" as having been proposed by him in all essentials, and there is evidence of his hand in many features, particularly in the bold departure in dimensions from unarmoured battleships, the use of iron instead of wood, and the adoption of structural arrangements in which longitudinal framing was prominent. This adoption of iron hulls, while the French adhered to wood for ten years longer, gave our Navy a great advantage, and disposed of many difficulties in regard to shipbuilding timber. With iron hulls, dimensions and engine-powers surpassing anything possible with wood were feasible. Already in the last wood frigates of high power there had been indications that 300 feet of length was near the limit for the type; but in the "Warrior" 380 feet was adopted, with a breadth of 58 feet, and a displacement of nearly 9,000 tons. She was frigate-built, carrying her guns in a battery on the main deck, protected by 4½-inch armour, and 18 inches of teak backing; the ends of the battery were closed by transverse armour bulkheads. The length of the battery was 213 feet, and the ends of the ship were unarmoured for a total length of nearly 170 feet. The French ironclads, previously mentioned, had their side armour carried to the bow and stern, and were therefore "completely protected," but they were much shorter. The most serious defect was that rudder and steering-gear were exposed in the "Warrior." As a steamer, her greater length and power gave her superiority. Her engines developed 5,500 HP. on trial, and she attained 14·4 knots. For a long period that speed remained a standard for ironclads. The engines and boilers were supplied by John Penn, and exemplified the latest advances in marine engineering. About 6 I.HP. per ton weight of propelling-apparatus was developed on trial. Horizontal engines of the trunk type were fitted, and the boilers gave 25 lbs. pressure per square inch. In earlier screw-steamers with lower steam-pressures and lower speed, 4 to 5 I.HP. per ton had been common.

As first designed the "Warrior" was intended to carry twenty-

six 68-pounder smooth-bore guns in the armoured battery, ten similar guns on the main deck outside the battery, and two as pivot-guns (bow and stern chase) on the upper deck. These were the most powerful smooth-bore muzzle-loading guns in our naval service, and the armament was very formidable. It has been stated that a screw three-decker of 1859 only carried one 68-pounder out of her 121 guns. But before the "Warrior" was completed another notable step was taken, and forty 110-pounder rifled breech-loading Armstrong guns were mounted, far superior in range, accuracy and penetrative power to the 68-pounder.

It will be seen from this statement that at one step 120 feet (46 per cent.) was added to the length of the largest unarmoured battleships, 2,000 tons (nearly 30 per cent.) to the displacement, 1,300 HP. (30 per cent.) to the engine-power, and 2 knots to the speed, besides an armoured battery and a much more powerful armament. The cost was increased to £380,000 (fully 70 per cent.). This was a novel type far exceeding in power "La Gloire" and her consorts, which were about 240 feet long and had a speed of 12 knots. Ample sail-power was given to the "Warrior"; she could lower her funnel and lift her screw-propeller, and proved as successful under sail as under steam. In her way she was no less remarkable than the "Great Eastern," and she was the next largest ship in existence for a time. In appearance she was most graceful, and her construction afforded proof that English naval architects need not fear comparison with their French professional competitors when they were given a free hand.

The First English Schools of Naval Architecture.

Fortunately for the nation there were many capable men ready to face and solve the new problems which arose when the long sleep of centuries ended and a revolution began in materials, methods of propulsion, armaments and protection. Yet, strange to say, in 1859 there was in this country neither an Institution devoted to the training of naval architects and marine engineers, nor an association specially devoted to the discussion of subjects relating to ship-design and building. There had been two English schools of naval architecture, both founded by the Admiralty and conducted with eminent success, while both were abolished by Sir James Graham, to whom also belonged the discredit attaching to the appointment to the post of Surveyor of the Navy—an officer then charged with the responsibility of designing

ships for the navy—of a naval officer eminent as a seaman but ignorant of the science of naval architecture. The trained naval architects of the first school included men like Isaac Watts (Chief Constructor during the steam-reconstruction), Lloyd (long Engineer-in-Chief), Creuze, who became Chief Surveyor of that great organization Lloyd's Register of Shipping, and Moorsom, who revised the Tonnage Law in 1854, after many others had failed, on a basis which has since become practically international. These men and their colleagues had long to wait for an opportunity to show their powers, and it was not until driven to the course by absolute necessity that the Admiralty gave them the recognition and position they deserved.

The first school was established in 1812 and abolished in 1830. A distinguished member of the University of Cambridge, Dr. Inman, was the Principal, and to him the English literature of shipbuilding is greatly indebted. The second school was established in 1848 and abolished about six years later. Dr. Woolley was the Principal, another eminent Cambridge graduate, who proved admirably qualified for teaching the science of naval architecture, and made many important additions thereto. His pupils included Sir Edward Reed and Sir Nathaniel Barnaby, who were in succession the responsible designers of Her Majesty's ships from 1863 to 1885; Mr. Barnes, who occupied for many years the post of Surveyor of Dockyards, and other men less prominently before the public who did good service to the navy during the first quarter of a century of the ironclad reconstruction. Dr. Inman's pupils were men of advanced age when that reconstruction became necessary, and entirely new conditions had to be faced. It is no reproach to their memory to say that the naval defence of the empire was more efficiently dealt with by younger men, fresh from a thorough training in the School of Naval Architecture, and subsequently prepared for the important appointments they had to fill by some years of practical work in shipyards and designing-offices. Another important change which had great influence was the appointment as Controller of the Navy of Sir Spencer Robinson, a naval officer of great ability, who was content to deal with questions of policy and administration, and to leave to naval architects the duty of designing ships to fulfil the conditions approved by the supreme authority of the Board of Admiralty. He showed throughout his long occupancy of that important office an intelligent and sympathetic interest in the work of the technical staff, but was careful to recognize its importance and distinct responsibility.

When such stirring events were in progress it was natural that naval architects and marine engineers should establish a Society, wherein could be discussed many important questions affecting the construction of ships, both for war and for commerce. In 1860 the Institution of Naval Architects was founded. Its earliest members included men who had been trained in both Schools of Naval Architecture, others holding high office in the Admiralty service, and many of the leading private shipbuilders and engineers. Its objects were to "promote the improvement of ships and of all that specially appertains to them," and it sought to do this partly by "bringing together those results of experience which so many shipbuilders, marine engineers, naval officers, yachtsmen and others acquire independently of each other." As Associates it welcomed naval officers, yachtsmen, shipowners, mechanical engineers and all classes "qualified either by profession or occupation or by scientific or other attainments," to discuss with naval architects the qualities of a ship or the construction, manufacture or arrangement of some part or parts of a ship or her equipment.

Sir Edward Reed was the first Secretary, and to his ability and persistent effort the Institution owed much of the immediate success it attained. Outside the Admiralty service, men like Laird, Samuda, Scott Russell, Napier, Penn, Maudslay, Rennie, Denny, Scott (of Greenock), White (of Cowes), the Chief Surveyors of Lloyd's, and other eminent shipbuilders and marine engineers, heartily supported the movement. Authorities in the science of naval architecture like Dr. Woolley, Dr. Moseley, and William Froude, added their names and gave active assistance. Rankine soon associated himself with them. A large number of naval officers also joined, and some shipowners and yachtsmen. The first President was Sir John Pakington, who had recently been First Lord of the Admiralty and signalized his administration by ordering the "Warrior."

The Institution thus launched at once gave proof of its utility and importance to the national interests and to the shipbuilding industry. It has continued to grow in numbers and influence, and to its action are due the fact that the reproach was soon wiped away that there was no proper means of education for naval architects and marine engineers, in the country which held the lead in shipbuilding and shipowning.

This imperfect sketch of the condition of British shipping and shipbuilding could not be more happily closed than by the statement that from 1860 onwards the science as well as the

practice of the profession has been adequately cared for by the Institution of Naval Architects, which has acquired an international character, and includes the most eminent naval architects and marine engineers of all countries.

Lines of Advance in Modern Ship Construction.

The preceding sketch of the condition of shipbuilding in 1859 indicates the unrest, change and controversy as to future naval construction which then prevailed. Marine engineering was rapidly becoming specialized and was breaking away from land-practice. The economic advantages of increased steam-pressure were being realized, direct-acting engines were gaining upon the earlier types copied from land-engines. Screw-propellers were becoming universal for ocean-going steamships, and the weight of machinery was diminishing in proportion to its power. An object-lesson of the potentialities of iron as a material for hull-structures was afforded by the "Great Eastern." This practically involved the gradual disuse of wood hulls, and showed that limits to the dimensions of ships need no longer be determined by the capabilities of the material, but might be governed by commercial or warlike considerations. New structural combinations followed upon the use of the superior material, and new processes and machinery became necessary in the shipyards. For war-ships of the first class, armour was admitted to be necessary as a protection against shell-fire. Armour-protection produced immediately a demand for more powerful guns, and the want was met by the genius of Armstrong and others. The types of smooth-bore muzzle-loading naval guns and mountings which had been used for centuries, gave place to rifled breech- and muzzle-loading guns of greater weight, power, range and accuracy, with new patterns of mountings. So began the incessant struggle, which has been waged between guns and armour ever since. All these changes coming almost simultaneously involved new problems of great difficulty for the naval architect and the marine engineer; while the mechanical engineer and the iron manufacturer had to meet fresh demands. Questions of stability, structural strength and propulsion, arose, to which experience could give no sufficient answer; and, as a consequence, scientific methods became necessary instead of "rule of thumb." The divergence between merchant-ships and war-ships was great already, but it was much accentuated by the introduction of armour and modern guns. While each class presented its difficulties, the war-ship designer probably had the

most complex problems to face, when called upon to produce armoured structures, mounting heavy guns, yet possessing high speed and good sea-going qualities. Still, it remained true that there was much in common between all classes of steamships : and the great lines of advance for all were based upon (1) improvements in marine engineering, leading to large economies of weight of machinery and fuel; (2) improvements in materials, both in regard to strength and to the forms in which they were furnished by manufacturers; and (3) the larger use of scientific methods in design. It may be interesting to glance at each of these dominating influences, and their effects on ship construction during the past forty-four years.

Improvements in Marine Engineering.

Improvements in marine engineering have produced the greatest effects, in the extension, and increase in speed, of ocean steam-navigation. The details of these improvements can be found in valuable Papers published in our "Proceedings" and elsewhere, the authors being men eminent in that branch of engineering, who have recorded, from time to time, the state of advancement and the contributory causes. The series fitly begins in 1872, with a Paper by Sir Frederick Bramwell, whose personal experience goes back to the earliest period of ocean steam-navigation, and whose interest is as keen as ever in the latest advances in the generation and utilization of power. All that will be attempted here is a brief summary of the principal features in an advance that has been striking and continuous.

Increase in Steam-Pressure.

In 1859, the highest steam-pressures used in marine boilers were from 20 to 25 lbs. per square inch; 20 years later 90 to 100 lbs. had been reached, and the "compound" (double-expansion) type of engine was in general use. Now in the mercantile marine, with the ordinary (water-tank cylindrical) boilers, pressures of 210 to 220 lbs. are common, and a little less than 270 lbs. has been reached in a few cases. For war-ships, with water-tube boilers, pressures of 250 to 300 lbs. have been used for 9 years; but in the most recent vessels, in which 20 per cent. of the total power is in cylindrical boilers, with the balance in water-tube boilers, the pressure adopted is only 210 lbs. With these high pressures, triple- or quadruple-expansion engines are associated.

There is a wide-spread feeling amongst marine engineers that, with cylindrical (or "tank") boilers, it is not desirable to exceed 220 lbs. per square inch as the steam-pressure; and, although quadruple-expansion engines are favoured for the highest pressures used in the mercantile marine, triple-expansion engines are made in much larger numbers. For ships of the Royal Navy, triple-expansion engines of the four-cylinder type are used, with two low-pressure cylinders and four cranks; and this is the arrangement adopted in many large-powered merchant steamships. With higher steam-pressures than 220 lbs., certain difficulties occur in the pipe-joints and other parts liable to leakages of steam. Defects which would be of no practical importance with lower pressures, then permit of losses of steam and other annoyances that cause many engineers to doubt whether, on the whole, it is worth while to go to higher pressures, such as 250 to 300 lbs. The objects aimed at, in accepting such pressures in ships of the Royal Navy, were economy in weight and bulk of the propelling-apparatus, and economy of fuel when engines of large power were working at low powers (for cruising-speeds). The latter economy would result from the engines being smaller than they could be with the same maximum powers and lower pressure. On the whole, these intentions seem to have been fairly realized in the main engines; but in the auxiliary engines the use of high steam-pressures has involved large expenditures of steam, as compared with that sufficing for the same types of engines with lower pressures. Moreover, in many instances there have undoubtedly been very considerable steam-leakages and losses of water. It will, therefore, be a matter of great practical interest to have the facts as to the relative economy of ships fitted with the combination of cylindrical and water-tube boilers, with 210 lbs. steam-pressure The first of these will soon be tried, and the results should be valuable.

Revolutions and Piston Speeds.

This rise in pressure and greater expansion have been accompanied by an increased rate of revolution and piston-speed. In 1859, for the best types of engines in screw-steamers the revolutions did not exceed 50, and the maximum piston-speeds were about 400 feet per minute. In 1881 the averages for merchant steamers were about 60 revolutions, with 470 feet per minute piston-speed; now the corresponding averages are nearly 90 revolutions, and over 650 feet, while many steamers of high speed attain piston-speeds of 900 feet to 1,000 feet. The "Deutschland,"

at first, is reported to have worked at about 75 revolutions with over 900 feet piston-speed; on her later service the revolutions have risen to over 80 per minute with 1,000 feet piston-speed when developing about 36,000 HP. with twin-screw engines. In war-ships the rates of revolution are higher and the strokes shorter than in merchant-ships. In 1881 the revolutions for battle-ships were about 80, and the piston-speeds about 650 feet to 700 feet per minute. Now they have been increased to 100 or 110 revolutions, with 850 feet to 900 feet piston-speed. For swift cruisers of large power, 120 to 140 revolutions and 1,000 feet piston-speed are now common: smaller cruisers have about 220 revolutions with equal piston-speed; destroyers have 350 to 400 revolutions and 1,100 feet to 1,200 feet piston-speeds.

It need hardly be remarked that these increases in revolutions were associated with a change from horizontal to inverted-vertical cylinder engines. The change was made in merchant-ships many years before it was adopted in war-ships, wherein it was considered important to give increased protection by placing engines and boilers below the water-line. When armour came into use this consideration became unimportant, and about 1873 vertical engines were adopted for battleships. For cruisers horizontal engines were used in the Royal Navy up to 1886. I adopted vertical engines in the torpedo cruisers "Panther" and "Leopard" designed and built at Elswick for the Austrian navy in 1884–5; and the results were so satisfactory that the same type was adopted in the "Medea" class which I designed for the Royal Navy in 1886. Now vertical engines are universally adopted in war-ships, including the smaller classes.

Weight in Proportion to Power.

Remarkable economies of weight, in proportion to power developed, have accompanied these changes. For war-ships the records are complete and continuous, and the valuable Papers contributed to the Proceedings [1] by the Engineer-in-Chief, Sir John Durston, and Engineer Rear-Admiral Oram, have put the facts on record. Taking the contractors' trials for the specified maximum power, it is found that each ton weight of propelling-apparatus (in full working order) gave about 6 I.HP. in 1859: whereas in present practice about 9 I.HP. is obtained in battle-ships with cylindrical boilers, and about 10·5 I.HP. with water-tube boilers. In large cruisers with water-tube boilers, such as the "Drake"

[1] Vol. cxxxvii. pp. 167 and 202.

class, about 12 HP. per ton is obtained: in third-class cruisers with water-tube boilers having thinner and smaller tubes, about 20 HP.: and in destroyers 40 HP. to 50 HP. The large cruisers have proved themselves capable of developing about 75 per cent. of their maximum power for continuous steaming at sea, which corresponds to 9 HP. per ton: for the small cruisers and destroyers 50 per cent. to 60 per cent. of the maximum power can be maintained, as long as the coal lasts: taking 50 per cent. this gives 10 HP. per ton weight for the cruisers, and over 20 HP. per ton for the destroyers.

War-ships differ from merchant-ships in one important feature, to which sufficient weight is often not attached. Their ordinary service is performed at low speed, with a very small percentage of their maximum power, and full speed is the exception. Long-distance passage trials are made at intervals, but usually not with more than 60 per cent. to 75 per cent. of the maximum power specified in the contracts for machinery. On the other hand, merchant-steamers are designed and engined to steam at full speed, and under fairly uniform conditions of development of power on all their passages. The swiftest of them run between certain terminal ports at regular speeds, except as affected by weather and sea. All this favours economy, and to ensure regularity of service it is reasonable that larger margins of weight in proportion to power should be allowed than in war-ships. Moreover, in many parts of the machinery of war-ships, sensible increase in first cost is accepted in order to reduce weight, since every possible saving in weight is of advantage. In mercantile practice this policy is not carried so far. Making allowance for these essential differences there have been great relative savings in the proportion of weight to power in mercantile steamships. In 1859 the best direct-acting screw-engines developed on service 3 HP. to 4 HP. per ton. Now the corresponding development is 6 HP. to 6·5 HP. per ton in swift mail-steamers of the highest class; in ordinary cargo-steamers 4 HP. to 5 HP.; and in cross-channel steamers making short passages with high forced-draught in the boiler-rooms, cylindrical boilers, and quick-running engines of short stroke, it rises to 10 HP. per ton. The last-mentioned conditions would not, of course, be applicable to long sea-voyages.

Forced Draught.

Forced draught in the boiler-rooms is an old invention, and for the last quarter of a century it has been largely used as a means of accelerating evaporation and increasing power. Previous

practice in torpedo-boats and small craft led to its application in larger vessels of all war-fleets. The "closed" stoke-hold system was chiefly used, powerful fans supplying air, and maintaining a positive pressure of varying amount according to the rate of evaporation required. With cylindrical boilers in ships of the Royal Navy the air-pressure does not exceed ½ inch of water for long-distance steaming, and 1 inch for short runs of 6 to 8 hours. Formerly 2 inches pressure was permitted, but the boilers suffered. With 1 inch pressure it is found possible to obtain, without injury to the boilers and for considerable periods, about 20 to 25 per cent. more than the "natural draught" power, without sensible decrease in fuel economy. When water-tube boilers are fitted, higher air-pressures are permitted in torpedo-boats, destroyers, and small cruisers; but in large cruisers and battle-ships the stoke-holds are not closed and air is supplied amply by means of powerful fans.

In the mercantile marine many systems of induced and forced draught have been employed. That which finds most favour was worked out by Mr. Howden. The stoke-holds are open, there are special fittings on the boiler-fronts for admitting and regulating the admission of air—supplied by powerful fans under pressure—both above and below the fires; and arrangements for utilizing heat, that would otherwise be wasted, in raising the temperature of air supplied to the furnaces. Lengthened experience supports the view that with this system large evaporative-power can be combined with economy of coal-consumption, so that the boiler-room weights can be reduced considerably. Mr. McKechnie stated in 1901 that nearly 3½ million HP. had been installed in ships fitted with this system, and that the rate of coal-consumption in successful vessels so fitted had been brought as low as 1¼ lb. to 1½ lb. per horse-power-hour.

Use of Steel in Marine Engines.

The marine engineer has been greatly assisted in economizing weight by the substitution of steel for iron in tubes, plates, forgings and castings. With the stronger material and the great improvements in manufacture which have followed the development of steel, he has had larger opportunities for skill in design of details of both engines and boilers. The mechanical engineer has also aided this result by the device of powerful machines for bending, flanging, drilling and riveting. A modern boiler-shop is radically different from that of twenty years ago in its appliances, methods and scale of operations. In engine design, an amount of

care is now bestowed on keeping down weights of details, such as was formerly unknown. For the highest class of engines the principle is established that greater first cost in shaping and machinery is more than compensated for, if considerable relative savings of weight can be secured, while maintaining strength. Hollow shafting and special forms of castings and forgings for engine-framing are only a few of many instances that might be mentioned of this practice. Underlying it is a close investigation, based on scientific and experimental methods, of the stresses to which the parts are subjected, and the best means of meeting them.

Economy of Fuel.

Higher steam-pressures and grades of expansion, combined with more efficient engines, have resulted in large economies of fuel. The best direct-acting engines in screw-steamships of 1859, with 20 to 25 lbs. pressure per square inch, required $3\frac{3}{4}$ to 5 lbs. of coal per I.HP.-hour. In the mercantile marine, about twenty years later, this had been reduced to about 2 lbs. as an average with compound engines; at present it is about 1·5 lb. for ocean-going steamships with triple- and quadruple-expansion engines. There are well-authenticated instances of long voyages having been performed under economical conditions with an expenditure of 1·25 to 1·4 lb., and in some of the fastest passenger-steamers 1·5 to 1·6 lb. For war-ships the proportionate expenditure of coal is somewhat higher than in merchant-ships, for reasons which need not be stated in detail; but on long trials, representing maximum speeds for continuous steaming, the average expenditure has been about 1·6 lb. to 1·8 lb. per HP.-hour, with the latest types, both of cylindrical and water-tube boilers, fitted on large ships. In third-class cruisers, with tubes of small diameter, the expenditure under similar conditions has averaged about 2·25 lbs. In destroyers, at maximum speed, it has varied between about $2\frac{1}{4}$ and 4 lbs. on short trials of 3 hours; and at speeds of 13 knots, requiring only about 7 to 8 per cent. of the maximum power, the expenditure has been 1·4 to 2 lbs. Mr. Normand claims to have obtained much superior results in his torpedo vessels, the expenditure at 30 knots being about $1\frac{1}{2}$ lb., and at 14 knots less than 1 lb. per I.HP.-hour, on trials of 3 and 8 hours respectively.

Economy of fuel is obviously of the greatest importance in ocean-going steamships making long voyages, and apart from the progress above described, steam navigation could not have been successfully developed over the longest sea-passages. There are still instances,

however, where economy in fuel has to be sacrificed to other considerations in order to obtain the best commercial result. Cross-channel steamers afford an excellent example. They have only short passages to make, at very high speeds; their dimensions have to be restricted, and space and weight are limited. Great power is required, and the problem is how to instal suitable propelling-apparatus. Small coal-supplies suffice; the coal-expenditure is relatively trivial. Forced draught is used in the boiler-rooms, and quick-running engines are essential. One of the Holyhead-Kingstown steamers, for example, develops 8,000 to 9,000 HP. when steaming 23 to 24 knots. She requires less than three hours for the passage, and if (on account of high forced-draught) an additional pound of coal per horse-power-hour were burnt, it would only mean 11 to 12 tons for each passage. The reduction in weight and space for engines and boilers, accompanying this extra coal-consumption, would obviously be much more important. The weight of propelling-apparatus is only about one-half that of an ocean-going steamer of equal power. As a contrast, take a trans-Atlantic liner carrying passengers and cargo, at an average speed of about 14½ knots, with engines developing about 9,000 HP. Here an increase of one pound per horse-power-hour would involve an additional coal-expenditure of about 850 tons for the passage, and reduce the freight-earning capacity by the same amount. No amount of "forcing" which could be prudently adopted in such a vessel, for continuous use on the voyage, would yield economies in weight of boilers worth notice in comparison with these disadvantages in fuel and freight.

THE "EXPRESS" TYPE OF MACHINERY.

The new departure made by Sir John Thornycroft about thirty years ago in the construction of small, swift boats, with engines and boilers of remarkable lightness in proportion to the power developed, has had a notable influence upon marine engineering generally. It seemed obvious that this must be so, and I ventured to express that opinion in the discussion on Mr. Alfred Holt's Paper[1] on Steam Navigation in 1877. No doubt Thornycroft was greatly influenced and assisted by the work of locomotive engineers, and we have here an illustration of the close relation and mutual aid of different branches of engineering. But he had to face many

[1] "Review of the Progress of Steam Shipping during the last Quarter of a Century," by Alfred Holt, M. Inst. C.E. Minutes of Proceedings Inst. C.E., vol. li., p. 2.

novel conditions in making this experiment, and to go entirely beyond precedent. His results were hardly credited in their entirety at first, but when established by capable and independent observers, they were full of suggestion as to further possibilities. Sir John Thornycroft has found worthy *collaborateurs* in Mr. Yarrow, Mr. Normand in France, Mr. Schichau in Germany, and Herreshoff in America. From his work have sprung the torpedo flotillas of the world; and the system of high-speed engines, excessively light in relation to power, has been made use of for the smaller classes of cruisers and cross-channel steamers by many other firms. Indeed, since destroyers were introduced, ten years ago, the construction of machinery of this type has been largely extended, with remarkable increases of speed. At first associated with a modified locomotive-type of boiler, it has now long been the practice to use water-tube boilers (small-diameter tubes) for all small war-vessels, and for some passenger-steamers; but in British-built, cross-channel and river steamers, cylindrical boilers are retained. In the "Warrior" of 1859 (engined by Penn), 5,500 I.HP. required 900 tons of propelling-apparatus; and this was a light engine for that time. The torpedo-boat destroyer "Desperate" (engined by Thornycroft in 1896), developed 5,800 HP. for 130 tons.

Steam Turbi-Motors.

The steam turbi-motor, first applied to ship-propulsion by Mr. Charles Parsons in the "Turbinia," enables a further saving of weight to be effected as compared with the quickest-running and lightest reciprocating-engines. There are other important advantages with the new motor: such as freedom from vibration, lessened expenditure on lubrication, upkeep and repairs, and reduced cost of supervision; but on these it is unnecessary to dwell. In the "Turbinia" extreme lightness was attained, the total weight of machinery, boiler, shafting, and propellers being 22 tons, for an estimated horse-power of over 2,000 HP.—nearly 100 HP. per ton of weight. This is about twice the power in proportion to weight as compared with a destroyer. The turbines make 2,000 to 2,200 revolutions per minute, as against 400 revolutions in the destroyer. This vessel had a boiler of special type which was forced considerably, and her runs at full power were of short duration: moreover, she had no reversing-turbines for steaming astern. These features of the design sensibly reduced the weight. Other examples of the turbine system, however, furnish a fairer comparison with reciprocating-engines, and make it certain that with a much lower rate of revolution than in the "Turbinia,"

and with additional turbines for going astern at good speed, it is possible to effect considerable proportionate economies of weight, or to increase speed. The destroyer "Viper," with turbine-machinery was practically identical in dimensions with other destroyers having reciprocating-engines, and she attained a maximum speed of about 36·6 knots on an hour's trial, and about 34 knots for 3 hours with the contract load on board. The latter speed is about 3 knots greater than the corresponding speed on some of the best of the similar destroyers with reciprocating-engines, and 4 knots above the guaranteed speed of the latter.

Messrs. Denny estimate that, if the Clyde passenger-steamer "King Edward" had been fitted with balanced twin triple-expansion engines of the best type instead of turbines, in association with the same boilers, the speed would have been reduced from 20·5 knots to 19·7 knots—corresponding to a difference of 20 per cent. in horse-power. In the steam-yacht "Lorena," of about 4,000 HP. to 4,500 HP., the original intention was to fit reciprocating-engines; by fitting turbines 70 tons were saved in the weight of the machinery, and the engine-room space was made much less. As several other vessels now building are to be fitted with turbines, including the Atlantic liner "Victorian" and a sister-ship of the Allan line, fuller information as to the relative merits of the system will soon be available.

As one who, from the first introduction of the steam-turbine by Mr. Parsons in 1884, has been intimately acquainted with his work and with the difficulties he has overcome in the application of turbi-motors to various purposes, I would testify to the great courage and ability he has displayed throughout. In regard to the special application of turbi-motors to ship-propulsion the difficulties have been greatest, and have only been surmounted by scientific and experimental work of the highest order. In addition there have been serious hindrances and disappointments in gaining experience, owing to the losses of both the "Viper" and the "Cobra." The Admiralty has given encouragement to the system ever since the trials of the "Turbinia" were carried out. In my official capacity, it was my duty to advise in regard to the adoption of the system in the "Viper," and later in the third-class cruiser "Amethyst" now building from my designs at Elswick. No one more heartily congratulates Mr. Parsons than I do that, at length, after 9 years of struggle, the system is being widely adopted, and is being seriously considered as to its suitability for the largest and swiftest vessels yet designed, the new steamers of the Cunard line.

Oil-Motors.

Another new departure now attracting much attention is the use of oil-motors in launches and small swift vessels. The remarkable results obtained in motor-cars as regards lightness in proportion to power of engines, and small weight of fuel in proportion to distance traversed, have led to the application of similar motors to certain small boats, and the attainment of very high speeds. In July last, after the Automobile Club car-races in Ireland, a contest took place at Cork between oil-motor launches, one of which is reported to have had an engine of 75 B.HP., while others had 50 and 20 B.HP. His Majesty the King, ready as ever to promote all improvements in yachts and ships, has had a launch built by Messrs. Tagg and engined by Messrs. Thornycroft, having a length of 32 feet, beam of 6 feet, draught 2 feet 9 inches, and an oil-engine of 20 B.HP. The maximum speed is said to be 13 miles an hour, and seventeen gallons of petrol are said to give the power to travel about 60 miles at a speed of 10 miles an hour. The consumption of oil on this basis is about 0·8 lb. per horse-power-hour, as against 2 to 2½ lbs. for a good steam-engine, such as is fitted in launches. It is further stated that such an engine, with petrol for 6 hours, weighs less than 6 cwt., as against about 3 tons for a good condensing steam-engine of the same power, with its boiler in working order and fuel for the same run. This would make the comparison of weight in favour of the oil-motor, and its fuel stand as 10 to 1. I am of opinion that 6 to 1 would be a fairer comparison for propelling-apparatus and fuel, and this is an enormous gain in favour of oil-motors. The effect upon speed of such lightness in proportion to power is necessarily very great. It is stated that a boat 30 feet long, 5 feet broad and about 2 feet deep, fitted with a 20-B.HP. oil-motor, has been constructed by Messrs. Thornycroft capable of attaining the remarkable speed of 18 miles an hour. The space occupied by this motor is not much larger than that required for a condensing engine of the same power, and the space required for boiler and coal is available for accommodation in the motor-launch. Gearing has been introduced for reversing when required, and it is a heavy item.

Mr. Edge, who is so well-known in connection with the manufacture and use of automobiles, has lately given much attention to the adaptation of oil-motors to launches and small craft. He has kindly furnished much interesting information as to results obtained, and practically confirms the foregoing statement both

for weight and fuel-consumption. The launch "Napier" is a remarkable vessel, 40 feet long, 5 feet beam, and about 7 inches draught. She has attained a speed of 19 knots (22 miles) per hour, the engine developing over 100 I.HP. The instantaneous photographs taken of this boat under these abnormal conditions are very interesting and suggestive. I understand that Mr. Yarrow is now commencing work in this class. Many years ago he constructed naphtha-launches of small size.

It is interesting to compare the results of Thornycroft's oil-motor launch with those obtained by the steam-launch "Miranda"—also built by Thornycroft—on speed-trials conducted by Sir Frederick Bramwell in 1872. This vessel was 45 feet 6 inches long and 5 feet 9 inches broad at the water-line; on trial she carried 3 cwt. of coal and had a displacement of 3¾ tons. She was fitted with a locomotive-boiler and a two-cylinder vertical engine, capable of working at 600 revolutions and developing about 72 HP. (indicated). With 555 revolutions and nearly 60 I.HP.—probably about 50 B.HP.—the vessel attained a speed of 18·65 miles per hour. The machinery and boiler weighed about 2 tons, so that at maximum power—600 revolutions—it developed about 36 I.HP. per ton weight of propelling-apparatus. The coal-expenditure, apparently, was not recorded, but it will probably not be far wrong to assume that the 3 cwt. of coal carried represented less than two hours' steaming at full speed, and that if six hours' supply had been carried the speed would have been much reduced. Neglecting this correction it appears that the oil-motor launch, although only two-thirds the length of the "Miranda," attained practically the same speed. The secret of her success lay in the fact that her propelling-apparatus, with fuel for six hours, gave about 65 I.HP. per ton. Obviously there should be the possibility of considerable developments in speed with such a motor as this.

Another interesting application of the oil-motor is to the propulsion, at the surface, of submarine boats. Lieutenant Dawson (of Messrs. Vickers, Sons and Maxim) states that in the first submarine boats of the "Holland" type built by his firm, the four-cylinder gasolene engines give a maximum of 190 B.HP., driving a single screw. The estimated speed at the surface was 8 knots, and the fuel carried is said to be sufficient for 50 hours at this speed (or 400 knots). When submerged, electric motors are used. It is reported that the actual speed obtained on trial was 9 to 10 knots for the first boats; and that in later and larger vessels the oil-motors have been much increased in power, with a

considerable increase in surface-speed. If this is correct it is probable that these vessels have the greatest power in oil-motors yet applied to ship-propulsion.

Reports have appeared recently that the Russian Government are now having made two sets of oil-engines, each of 6,000 HP., in order to test their value as applied in a twin-screw torpedo-boat destroyer; that the total weight will be 100 tons for 12,000 HP., and the fuel-consumption less than half a ton per HP.-hour. These statements are not officially authorized, but they indicate that the possibilities of the new motors are receiving attention abroad as well as in this country.

There is, of course, one danger to be guarded against in the use of such motors, namely, that there shall be no leakage of vapour or formation of an explosive mixture. There have been reports of accidents of this kind in submarines, and obviously in any closed-in space special precautions are necessary if accident is to be avoided. This will no doubt be dealt with, and for small craft oil-motors seem to have an assured future. To what extent their use will go, and to how great a power they will be carried, it is not easy to predict.

Gas-Engines.

The progress made in recent years with gas-engines of increasing power naturally raises the question whether they may not take the place of steam-engines even in large ships. No one can fail to be attracted by the prospect of possibly dispensing with the use of steam as an intermediary, and directly using gas for internal-combustion engines. Of course in sea-going ships questions of importance arise as to the power of covering long distances, and the arrangements for generating or storing gas, as well as obtaining adequate supplies of coal or oil. We are on the threshold of this subject; and it seems probable that a great deal more must be done on land in the development and use of gas-engines of very much greater power than any yet constructed, before the steam-boiler disappears from ships. Experiments of the character needed must not and need not be conducted on board ships. It may be that Sir Frederick Bramwell's prediction is correct, and that in less than 30 years the use of gas-engines will be almost universal. Only time can settle this question; but one thing is certain, naval architects and marine engineers will welcome and utilize any system which simplifies internal arrangements and minimizes weight and space.

Enthusiasts dream of a time when gas-turbines instead of reciprocating-engines shall be brought into use. Those more competent to judge than myself appear disposed to think that very serious, if not insuperable, difficulties lie in the way of this system of utilizing power. However this may be, no initial steps seem to have been taken to practically realize the idea.

Twin-Screws.

A notable feature in modern steamship construction is the largely extended use of twin-screws. This system was proposed in the earliest days of steam-navigation, and it was adopted practically half a century ago on a small scale. Between 1860 and 1865 a considerable number of twin-screw vessels were built, mostly vessels in which high speed was desired on moderate draught of water. These included a number of blockade-runners built during the American Civil War, and their success led to strong advocacy of an extension of the system to other classes, including deep-draught ships and more especially war-ships. The Admiralty, in this period, ordered two twin-screw armoured gun-boats, and one small light-draught ironclad, the "Penelope." A few foreign war-ships were also fitted with twin-screws at this time. Nearly all ocean steamers and war-ships, however, had single screws, and so long as sail-power was regarded as of great value, twin-screws were not favoured generally; partly because they greatly interfered with efficiency under sail, and partly on account of dependence on sail in case of a breakdown of the machinery. In 1866 the ill-fated "Captain" was laid down with twin-screws, and was followed soon after by four vessels of the "Invincible" class; some coast-defence vessels which had no sail-power were also fitted with duplicate propellers. When the so-called "mastless" type of sea-going ironclads was introduced in 1869, with no sail-power, recourse was necessarily had to twin-screws as a security against total breakdown; the fact being fully recognized, which has in recent years been repeatedly demonstrated, that a twin-screw ship could make fair speed and be perfectly under control with only one engine and screw at work.

Experience with these vessels and with the last rigged ironclads ("Alexandra" and "Temeraire") enabled me in 1878 to make an extended analysis of their propulsive efficiency, and a comparison with that of a number of single-screw ships of recent construction and deep draught. My conclusion was that, on the whole, the

efficiency of the twin-screw ships was superior: which was contrary to the opinion generally entertained at that time. The advantages possessed by twin-screws in giving increased security in case of disablement of propelling-apparatus, greater manœuvring power and greater facilities for watertight subdivision, were not disputed. But the suggestion which I ventured to add, as the result of my investigation, that twin-screws might be used advantageously in mail- and passenger-steamers of deep draught, and that they would give distinct advantage in regard to efficiency of propulsion, as well as increased safety, was not favourably received. My opinion was that, although, with the speeds and powers then accepted for the swiftest mail steamers, efficient single screws could be fitted on the existing draughts of water, yet better results in propulsion would be attained with twin-screws. The smaller diameter of the latter would increase the depth of submergence; they would consequently be less affected by the pitching movements of the ships in rough water, and speed would be better maintained. Looking to the future, I expressed the conviction that the inevitable increase of speed demanded would necessitate the large increase of engine-power, and so make the adoption of twin-screws imperative. These opinions were not favourably received at the time. It was, in fact, hinted that my opinions in regard to war-ships were probably more valuable than those respecting possible improvements in merchant-ships. But it is pleasant to note that the opinions expressed twenty-five years ago have been fully justified in later practice.

Little was done towards adopting twin-screws in mail-steamers for 8 or 9 years. Then came the question of realizing 20 knots on the Atlantic service; and my friend, the late Mr. Thomas Ismay, who had carefully studied my statements of 1878, consulted me when the design of the "Teutonic" and "Majestic" was being prepared by Messrs. Harland and Wolff. Enlarged experience had only confirmed my conviction and emphasized my recommendation of twin-screws. They were adopted in the ships named, and in the two 20-knot ships built for the Inman line about the same time, the "City of Paris" and "City of New York." From that time it was certain that twin-screws would take the place of single screws for swift mail-steamers. On some lines, where the speeds and powers are moderate compared with those on the Trans-Atlantic service, single screws continued to be used, and for vessels passing through the Suez Canal it was long maintained that twin-screws were unsuited because of their greater exposure and liability to damage. The successful passage through the canal of several large twin-

screw war-ships disposed of this fear, and the enterprise of the Orient Steamship Company in building the twin-screw ship "Ophir" in 1891 showed the way to other lines. Now all the great liners to the east are twin-screw, and on the Cape and Pacific services twin-screws have been adopted for all recent vessels.

There are, of course, great advantages in the subdivision of the power into two engines, as regards the reduced weights of moving parts, the smaller sizes of cylinders, shafting, and other items, all of which render manufacture more easy and tend to reduce stresses and vibration. In the swiftest ships with very high powers, duplication is a necessity from the side of propeller efficiency and from that of manufacturing capability. A few ships with twin-screws have been fitted with two sets of engines on each shaft. The cruisers "Blake" and "Blenheim," of 20,000 HP., built from my designs in 1888, were so arranged. In that case the object was to disconnect the forward engines on each shaft when working at low speeds, in order to reduce frictional and other losses on the engines and to economize fuel. A similar arrangement was made in the Italian battle-ships of the "Sardegna" class, also of 20,000 HP., built about the same time. The most recent example of the system is in the German Trans-Atlantic steamer "Kaiser Wilhelm II.," which began her service this year. Her engines develop on service about 40,000 HP., which has to be utilized on two screws, and these are of nearly 23 feet diameter. The diameters of the crank-shafts are 20·9 inches for the forward engine, and 25 inches for the after engine. There is a general feeling that this ship marks the furthest step likely to be taken in applying power to twin-screws driven by reciprocating-engines, and that if larger powers are so applied triple shafts and screws will be required. The greatest power applied to British twin-screw merchant-steamers is found in the "Campania" and "Lucania," viz., 28,000 HP. to 30,000 HP. on service. Thirty-one thousand horse-power has been developed and efficiently utilized in the "Drake" class of the Royal Navy (built from my designs in 1899–1901) on screws of only 19 feet diameter, the draught of water being 26 feet; and a speed of 24 knots has been attained.

Twin-screws have won their way also into extensive use for ships of great size, where moderate speed demands only comparatively small engine-power, and where every effort is made to increase economy. They have been applied successfully to cargo-steamers of 28 feet to 30 feet load-draught, and 11 knots to 12 knots speed, developing on service only 4,000 HP. These vessels are necessarily subjected to great variations in draught,

and the small diameter of the twin-screws maintains economy of propulsion better than a single screw could do under such variations, as well as in bad weather. Furthermore the increased safety against breakdown, and increased handiness, are important factors. Gradually twin-screws are gaining favour for smaller vessels, and as an example, reference may be made to the "Cluny Castle," an intermediate steamer of the Union Castle Line, of 432 feet in length and 5,000 tons, with engines developing about 3,500 HP. For all classes of war-vessels, from the largest battleship to the destroyer, twin-screws have been adopted in the Royal Navy for many years.

Triple and Multiple Screws.

Triple and multiple shafts and screws have also been used for long periods in exceptional cases where shallowness of draught governed the dimensions of propellers. Cases in point are the floating batteries for river service, built during the Civil War in America, with four shafts, the Russian circular ironclads, which had six shafts, and the Russian Imperial yacht "Livadia," which had three shafts. This remarkable vessel was 235 feet long, 153 feet broad, 18 feet draught, and 4,400 tons displacement; with 12,350 HP. she attained a speed of 15¾ knots. As compared with the circular form, she required only 60 per cent. as much power, but as compared even with short, bluff-ended ironclads, she required about 50 per cent. more power. In recent years triple screws have been used in war-ships built in the United States, France, Germany and Russia, but not in ships of the Royal Navy, except turbine-propelled vessels of small size. A few turbine passenger-steamers and yachts have been recently built with triple screws, and it is understood that this system will be adopted in the new Allan liners. In some turbine destroyers four shafts and eight propellers have been adopted, and the "Turbinia" had three shafts and nine propellers. All these vessels have had the propelling-arrangements designed with special reference to the design of the turbines, and their extremely high rate of revolution. In relation to dimensions and draught, very high powers have been developed, and considerable difficulty has been experienced in the selection of suitable propellers, capable of efficiently utilizing the power. The cases are special, but very suggestive of conditions which may become general. Screws of small diameter suffice under the circumstances, and this is distinctly advantageous to the application of the turbine system.

In the United States, after building, about ten years ago, two triple-screw ships of 19,000 HP. to 20,000 HP., which were reported to have done well, and, in face of the strong advocacy of the extension of the system by the Engineer-in-Chief (Admiral Melville), twin-screws have been preferred for later battleships and cruisers up to 25,000 HP. The Italians, after trials of triple-screws in small vessels, have universally adopted twin-screws. In France and Germany triple-screws are generally adopted for battleships and cruisers; in Russia a number of triple-screw cruisers have been built, but the great majority of ships have twin-screws.

Having been personally responsible for the continued use of twin-screws in His Majesty's ships up to 1902, it may not be out of place to put on record the reasons for that action, more especially as there have been repeated misrepresentations of the facts by ill-informed persons, whose fundamental idea seems to be that foreign practice must necessarily be superior to British, and that nothing but sheer obstinacy can account for a refusal to follow the lead of foreign designers.

At first it was claimed that triple-screws gave better propulsive efficiency than twin-screws. Having had exceptional opportunities of making a thorough and extended analysis of the actual performances of many ships, I have to state that this is not the case. The advantage, in this respect, is distinctly with twin-screws so far; and although it is possible that, with larger experience, the performance of triple-screws may be improved, and approach, or equal, that of twin-screws, it is practically certain that, under existing limitations of draught, and with reciprocating-engines making the number of revolutions and piston-speeds now accepted, there is no reason why triple-screws should be preferable to twin-screws up to 40,000 HP. There are many instances of distinct inferiority in triple-screw ships, and my foreign friends, who are building these vessels, admit this, urging that there are compensating advantages.

Of course, with three shafts and engines the manufacturing difficulties are less than with two shafts and engines. This was avowedly the reason why the two triple-screw American cruisers were built; but the great development of steel manufacture in the United States has removed that difficulty. Another gain by having three engines is said to be the possibility of running them faster and reducing the sizes of parts, thus saving weight and increasing economy of fuel when the vessels are cruising at low speeds. There may be some weight in this argument, but it is not of

primary importance, and experience seems to show that with triple-screws much greater power has to be developed at cruising speeds than is needed with twin-screws. Still another argument, and one most relied upon apparently by advocates of triple-screws, is, that at these cruising speeds it is possible to throw one or more engines out of work, and so to avoid losses on engine-friction, condensation, etc., thus economizing coal. Here there has been repeated change of ground, as trials have shown the fallacy of the contention. First, all three engines were made of equal size, and this is still the general practice. It was intended that at low speeds only the centre engine should be at work, and that the two side-screws should be disconnected and allowed to revolve. On trial, I am credibly informed, and can well believe, that the "drag" of the wing-screws added so seriously to the resistance that the power required for a given speed was 40 to 50 per cent. greater than that required when the centre screw was stopped and the side-screws worked. Obviously under these circumstances the centre-screw also caused a "drag," and more power was needed than in a purely twin-screw ship.

The Russians, in the "Rossia," followed this idea to its logical conclusion, and made the wing-screws and engines large enough to utilize the full steam-power at maximum speed, making the centre engine only large enough to drive the ship at 10 knots, and fitting a feathering-screw on the centre shaft. On trial this intention was realized, and the ship attained 10 knots with the side-screws disconnected and revolving, the centre engine developing nearly 3,000 HP. This compared most unfavourably with the performance of the cruisers "Powerful" and "Terrible," in the design of which I adhered to twin-screws. These ships are of 2,000 tons greater displacement than the "Rossia," but working both screws they require only 2,000 HP. for 10 knots and are much more economical. Their engines, moreover, have a maximum power of 22,000 as against 16,500 HP. in the "Rossia," and they are about 2½ knots faster.

In view of these facts another alternative has been proposed by Admiral Melville, viz., to make the centre engine large enough to develope one-half of the total power, and the side engines each to develope one-fourth of the power. So far as I am informed this plan has not been tried, and there seems no sufficient reason for making the experiment. His colleagues on the Board of Construction in the United States evidently were not convinced, and the responsible designers of triple-screw ships in France and Germany have not adopted the suggestion. The conclusion reached by most naval architects confirms the opinion I have

expressed, that, up to date, twin-screws are to be preferred and give better propulsive efficiency; while experience demonstrates that with proper forms of ships excellent manœuvring qualities can be secured. Against breakdown, no doubt, triple-screws give one more chance of avoiding total disablement, but large experience shows that for all practical purposes twin-screws give a sufficient margin of safety. Triple-screw engines also require greater space.

In conclusion, may I quote a few words written ten years ago? "It is reasonable to suppose that as higher speeds are attained and larger powers have to be utilized, since the limits of draught for ocean-going steamers are fixed by practical considerations, triple-screws may become necessary to efficiency." In my judgment that point has been reached; and the use of turbine engines with higher rates of revolution will also render desirable the adoption of three or four shafts, although the diameters of screws will be made relatively smaller. From first to last my desire has been to keep an absolutely open mind on this and all other questions affecting the efficiency of our war-fleet. No pains have been spared to ascertain and analyse facts; every suggestion for possible improvement, from whatever source arising, has been welcomed and carefully considered, and every endeavour made to arrive at the right conclusion, but the responsibility for decision necessarily rests with the designer on questions of resistance and propulsion, and that responsibility I have never attempted to avoid.

WATER-TUBE BOILERS.

The last advance in marine engineering to which reference will be made is that connected with the use of water-tube boilers. Boilers of that type have been in use on land for many years with complete success. Their employment on board ship has been proposed repeatedly, their relative lightness and the ease with which they can be shipped or removed being very advantageous features; while their superior safety, when using steam of high pressure, is universally admitted. Trials have been made of water-tube boilers afloat, and Sir Fortescue Flannery summarized the results of English practice in our "Proceedings"[1] 25 years ago; they proved unsatisfactory, and some time passed before further trials of the system took place in this country. In France, for reasons that are well understood, a much larger use has been made of water-tube boilers on land. With this experience

[1] Vol. liv. p. 123.

it was natural that Mr. Belleville, one of the leading manufacturers of such boilers, should desire to fit them on board ship. Between 1855 and 1878 many small vessels were fitted with his boilers, and successive improvements effected. In 1879 a trial was made on the French despatch-boat "Voltigeur" of 1,000 HP., with a greatly improved type of boiler. In 1884–5 my friend, the eminent naval architect, Mr. Bertin, adopted Belleville boilers in his design for the cruiser "Milan" of 3,800 HP., and similar boilers were fitted in the Messageries Maritime steamer "Ortegal" of 1,800 HP. After that date the use of water-tube boilers in French ships rapidly advanced; and in 1892, when I visited the French ship-yards, I found nothing but water-tube boilers contemplated for new war-vessels, from the smallest torpedo-craft to the largest battleships. The Messageries Maritimes also were fitting Belleville boilers on all their largest mail-steamers, up to 480 feet in length, 8,500 tons displacement and about 8,000 HP.

In this country a new departure had been made before that date, but for torpedo-boats and torpedo-gunboats only. As the modified locomotive-boilers used in torpedo-boats were increased in size and power, or grouped, serious difficulties arose. The most striking instance of this occurred in the torpedo-ram "Polyphemus," designed in 1877. Twelve locomotive-boilers were fitted, intended to give 5,500 HP., and according to torpedo-boat and locomotive practice this should have been easily accomplished; but repeated trials led to the conclusion that the attempt was hopeless, and other boilers were eventually fitted. Under these circumstances it was natural that attention should be redirected to water-tube boilers for torpedo-vessels of small size and high speed. Thornycroft and Yarrow in this country, Du Temple and Normand in France, Herreshoff in America and other engineers attacked the problem and devised various solutions. The condition of the question in 1889 can be seen from an excellent Paper contributed to the "Proceedings"[1] by Sir John Thornycroft. From that time onwards the "express" water-tube boiler, with tubes of small diameter, was extensively used for torpedo-boats; but it is interesting to note that when the first destroyers were ordered (1892) some of them were built with locomotive-boilers. The "Sharpshooter" class of torpedo-gunboats (designed in 1888) was also fitted with groups of locomotive-boilers; but one of the latest of the class, the "Speedy," of 4,500 HP., was (1892) fitted with Thornycroft water-tube boilers, and in consequence proved a much faster and more economical steamer. Up to 1892, however,

[1] Vol. xcix. p. 41.

no attempt was made to fit water-tube boilers in any other vessel of the Royal Navy above the size of torpedo-boats and destroyers.

My visit to France that year greatly impressed me, and the opportunities I then had of conferring with leading French naval architects and marine engineers convinced me that the position demanded serious consideration. These gentlemen, whose professional ability and experience were unquestioned, while their desire to avoid undue risk was obvious, had arrived at the conclusion that experience with Belleville and other water-tube boilers justified the exclusive use of that type. The Belleville boiler had then been tried afloat to some extent for 37 years, and was chiefly used in the vessels building at that time; but the Niclausse and D'Allest boilers were also receiving trial. This was a great experiment, no doubt, but made after full consideration. Its result, if successful, was to give to the French fleet a definite superiority in speed over British ships, if we persisted in using cylindrical boilers. The statement was made also, that no loss in economy of fuel was involved in the change to water-tube boilers, trial results being quoted in support of this statement.

On my return I reported to the Admiralty in this sense, and suggested thorough inquiry. This action was approved, and carried out by the Engineer-in-Chief and his staff. It is a matter of public knowledge that the investigation was made by officers of ability and experience, who obtained independent and trustworthy information as to the construction, weights and performances of various types of French water-tube boilers, having tubes of large diameter, and adapted for use in ships of considerable size and power. A naval engineer made a voyage to Australia and back in French mail-steamers of the first class in order to watch the practical working of Belleville boilers. Every possible step was taken to obtain information as to the merits and demerits of the boilers adopted in the French Navy, including upkeep and durability. A departmental Committee on boilers was then sitting, to whom the facts available were communicated, and they recommended a trial of the Belleville boiler. The Engineer-in-Chief endorsed this recommendation, and it was arranged that Messrs. Belleville should supply and fit boilers of their type to the "Sharpshooter," whose locomotive-boilers had been proved incapable of giving anything like the specified power.

Soon after (in 1893) I began work on the design of the cruisers "Powerful" and "Terrible," vessels which were intended to surpass in speed and power all foreign cruisers then built or building. The superior results in speed obtainable with water-

tube boilers necessarily received careful consideration; and various alternatives were compared before the boiler-arrangements were decided. As a matter of historic interest, it may be mentioned that my first sketch-design embodied a combination of a small number of cylindrical boilers, capable of developing about one-fourth of the maximum power, with a larger number of water-tube boilers. This plan was set aside after consideration; chiefly on the ground that, since the stoking for the two types of boilers would have to be entirely different in character, it was preferable to use only one type. The coal-endurance was estimated on the basis of reports of long-distance trials made in France; and it was closely approximate to the results obtained with the completed ships.

The magnitude of the experiment was fully appreciated by all concerned. The Engineer-in-Chief (Sir John Durston) finally recommended Belleville boilers, with which much greater experience had been gained than with any other type of water-tube boiler. I concurred with his recommendation, and gladly accept my share of the responsibility. The Board of Admiralty approved, and the orders were placed. There is, I submit, no reason whatever for regret or apology in the light of subsequent events for the action then taken. On the contrary, in my judgment, it has had greatly beneficial results for the Royal Navy itself, and will have far-reaching effects upon steamship-design generally. So much misunderstanding, to say the least, has arisen in regard to the circumstances under which the introduction of water-tube boilers took place, that it seemed desirable to place the facts on record.

Ten years have elapsed since the change was begun; it has since been carried through not merely in the Royal Navy, but in all war-fleets. The French have the honour of initiation; in this country we have not blindly followed their lead, but have taken our own way. At present no war-ship is building in which water-tube boilers are not either exclusively used, or associated with a few cylindrical boilers developing about 20 per cent. of the maximum power.

Into the controversies of the last four years I do not propose to enter. Hitherto, on account of ill-health and for other reasons, I have refrained from any public utterance on the subject. All that is necessary now is to state my conviction that those who have taken the most prominent part in attacking the policy of the Admiralty have exhibited an imperfect knowledge of facts and principles; have failed to appreciate the weight of authority against their contention—represented by the universal agreement

of naval authorities in all countries—that water-tube boilers are essential to modern war-ships; and have shown, in many instances, a spirit of prejudice and personality that should never have been displayed in the discussion of a technical subject affecting the naval defence of the Empire.

My personal attitude in this matter was explained here more than 4 years ago, and has been maintained throughout. Mistaken I may be, but I claim to have been consistent. Speaking in this Institution in March 1899 (at the close of a discussion on water-tube boilers) I said:—"Everyone agrees that the water-tube boiler—not meaning any particular boiler—is the safest boiler to use with high pressure. Everything in both the Papers points to the circumstance that, as yet, the perfect water-tube boiler has not been found. I should like to know how it is ever likely to be found if experiments are not made." My feeling is and always has been that it would be folly for us to remain inert while foreign navies were moving on lines promising great possibilities of advantage; and that, so long as we took only equal risks with them, experiments involved no loss of relative standing. I have always maintained that experiments on various types, having features of the greatest promise, were not merely desirable but absolutely necessary. Foreign critics make no assertion that we have prejudiced our relative position by the general adoption of water-tube boilers. Everyone who studied the last naval manœuvres must have seen how superior was the steaming capability of the most modern battleships and cruisers compared with those of earlier date with cylindrical boilers. As all the ships which were comparable were built from my designs, the comparison is narrowed to that of the propelling-apparatus, and the practical conclusion is irresistible.

The position has been made clearer by the investigation and finding of the Departmental Committee on water-tube boilers appointed by the Admiralty 3 years ago. No one can dispute the ability, and I am convinced of the impartiality, of this body. It is an honour to this Institution that so many of those who have rendered valuable service to the country under circumstances of great difficulty are our fellow-members, eminent both for scientific and technical attainments. It would be too much to expect that their conclusions will command universal assent, but it is unquestionable that these conclusions rest on a great series of experimental trials, and a close scrutiny of evidence. No attempt will be made to recapitulate these conclusions; they are to be found in many blue-books, well deserving study by all interested in ship construction and propulsion.

The Committee reported that, in their opinion, as the Belleville boiler was the only large-tube type which had been tried at sea on a considerable scale when the "Powerful" and "Terrible" were designed, there was justification for then regarding it as the most suitable type for the Navy. Further, they were of opinion that "the advantages of water-tube boilers for naval purposes are so great, chiefly from the military point of view, that, provided a satisfactory type of water-tube boiler be adopted, it would be more suitable for use in His Majesty's Navy than the cylindrical type." They recommended that no more Belleville boilers should be ordered, and that four different types of large straight-tube boilers should be fitted to new ships and subjected to thorough trial, viz., the Niclausse (largely used in France), the Dürr (a similar type extensively used in Germany for naval purposes), the Babcock and Wilcox (an American invention originally largely used for land purposes but introduced on an extensive scale for sea-service also and manufactured here), and the "Yarrow" boiler. It is hardly a matter for satisfaction that only one of the four types recommended, has an English origin. I am sufficiently "insular" to rejoice that there appears to be a good prospect of its success and extended use in our Navy. It has already been adopted in many foreign ships of war.

The last recommendation of the Committee that will be mentioned is as follows: "It appears that no type of water-tube boiler at present in use is, on general service, as economical as the cylindrical boiler; also that a large percentage of the coal used is expended for auxiliary purposes in harbour." "Until a thoroughly satisfactory type of water-tube boiler is obtained," it is considered desirable to fit cylindrical boilers capable of giving a small proportion of the power sufficient for low cruising-speeds and for auxiliary machinery. This is the arrangement contemplated in my sketch-design for the "Powerful" and "Terrible" in 1893, and then set aside. It involves the reduction of pressure for all the boilers to 210 lbs., and no doubt this reduction will lessen steam-losses. This recommendation has been approved and acted upon by the Admiralty in the ships ordered recently. It is evident that the Committee anticipate that eventually a thoroughly satisfactory type of water-tube boiler will be found; and that the cylindrical boiler will then disappear from war-ships.

The Papers of 1899[1] in our Proceedings give full details of the

[1] "Water-tube Boilers for Marine Engines," by J. T. Milton; and "Recent Trials of the Machinery of Warships," by Sir A. J. Durston, K.C.B., R.N., M.Inst. C.E., and H. J. Oram, R.N., M. Inst. C.E. Minutes of Proceedings Inst. C.E., vol. cxxxvii. pp. 167 and 202.

characteristic features of water-tube boilers and the machinery of modern war-ships. It is there made clear that water-tube boilers are much lighter, as well as safer, than cylindrical boilers. Competent authorities in mercantile engineering then certified that a saving of 40 per cent. in weight of boilers and water could be ensured if the water-tube type were fitted in swift mail-steamers. My investigations fully confirm this estimate. If it were applied to a steamship developing 40,000 HP. on service, it would mean a saving in boiler-weights of about 1,500 to 1,600 tons, and the possibility of an equal increase in freight-earning capacity if the rate of coal-consumption was not increased. In war-ship practice the corresponding saving has been about 33 per cent. Lighter types of cylindrical boilers are adopted on these vessels than are usual in mercantile steamers.

On the other side, of course, must be put the possible increase in coal-consumption on service. The Committee do not give figures for this, although they are convinced that the cylindrical boiler is more economical, especially after the boilers have been on service for some time.

An examination of the competitive trials between the "Minerva" and "Hyacinth" appears to show practical equality in coal-consumption; but the "Minerva" had been on service some time, while the "Hyacinth" was fresh from dockyard hands and in perfect order. There is other and quite recent evidence, however, of great interest, and I am enabled to give the figures by the courtesy of the Controller of the Navy. The cruisers "Spartiate" and "Europa," fitted with Belleville boilers, have recently made voyages to China and back. On the voyage out the "Spartiate" averaged 12·65 knots, steaming easily and developing less than 20 per cent. of her full power. Her average coal-consumption for all purposes was 2·29 lbs. per I.HP.-hour. The "Europa" was sent out at a still lower power, about 13 per cent. of the maximum, the average speed being 10¾ knots. Her consumption was, therefore, higher, viz., 3·85 lbs. per HP.-hour, and she burnt on the passage nearly 700 tons more than the "Spartiate." This demonstrated the fact, previously well understood, that, for covering distance, the higher speed was more economical in a ship of the type with great engine-power. But the most interesting fact remains to be stated: the "Spartiate" burnt nearly 1,200 tons less on the voyage than the "Blenheim" did on the same voyage, the latter being 2,000 tons smaller in displacement and having cylindrical boilers. The "Europa" burnt nearly 500 tons less. Allowing for differences of size and speed, the "Spartiate" is

more economical than any modern cruiser with cylindrical boilers that has made the passage.

The concluding run for both ships was made from Gibraltar to Plymouth on the homeward voyage. The "Europa" averaged 17·56 knots and consumed 2·06 lbs. of coal per horse-power-hour for all purposes, with 1·88 lb. for the main engines; the "Spartiate" averaged 18·11 knots with 1·7 lb. consumption for all purposes, and 1·52 lb for the main engines. At the end of such a voyage these were very good performances, comparing favourably with the consumption of the most modern types of cruisers fitted with cylindrical boilers. No doubt greater economy is secured in mail- and passenger-steamers, but the only fair comparison is between war-ships with cylindrical and water-tube boilers, the mercantile conditions being so radically different, as already explained.

The "Challenger," fitted with Babcock and Wilcox boilers, on her recent contractors' trials had the moderate and uniform consumption of $1\frac{3}{4}$ lb. per horse-power-hour at full power, and at 80 per cent. and 20 per cent. of full power: the ship was new, and everything, of course, in perfect condition. I am informed by its representatives that this company is prepared to guarantee equal economy with cylindrical boilers in merchant- as well as war-ships, provided they secure efficient conditions of stoking. No doubt careful management counts for much in the economy of water-tube boilers, and they suffer more from rough and improper usage than cylindrical boilers. The "human element" counts for much in the economical management of boilers of all types, and the long-accustomed use of cylindrical boilers tells in their favour. With water-tube boilers, altogether different conditions of stoking are essential to economy. In war-fleets stokers are specially trained and under discipline, so that the different style of stoking is carried out. In our mercantile marine it appears to be difficult to secure equal control and efficiency. From statements made by German authorities, and confirmed by British ship-owners, the German steamships have a substantial advantage arising from their better class of stokers and superior discipline. If this is so, the inferiority on our side should be remediable. In the engine-rooms of modern ships it is recognized that improved machinery needs greater skill and a higher class of men in charge. So in boiler-rooms the more delicate water-tube boilers demand more skilled and careful treatment. But surely mechanical improvement and economy in weight ought not to be sacrificed, by treating such a change in

stokehold staffs as an impossibility; it is well worth paying for.

The first trials of the Yarrow large-tube boiler in the "Medea" under the direction of the Boiler Committee are incomplete, and the results as to coal-consumption are therefore not available. It is understood, however, that in this respect there are good prospects of very satisfactory results.

The Niclausse type of boiler for marine purposes is made in this country by Messrs. Humphreys and Tennant, who have received orders from the Admiralty for an aggregate of over 100,000 HP. distributed over four cruisers and one battleship. One of the cruisers has passed through her trials with great success. Experience on service has yet to be gained.

The most recent orders for boilers for His Majesty's ships are reported to be divided principally between the "Yarrow" and "Babcock and Wilcox" types, and it would appear therefore that these are for the moment looked upon as the most suitable types available. Babcock and Wilcox boilers aggregate over 180,000 HP., and Yarrow boilers aggregate 130,000 HP. at the present time, in the Royal Navy. Valuable information will be obtained from the trials of all three types. The experiment is on an extremely large scale; but we cannot stand still, nor would any responsible and well-informed person now recommend cylindrical boilers for cruisers or battleships. Other navies are similarly circumstanced, and out of these trials here and abroad will come the data for deciding on the most efficient type of water-tube boiler.

Experience during the last 10 years with water-tube boilers fitted in British merchant-ships has not been extensive. It has been almost limited to the Babcock and Wilcox type. One Belleville-boilered ship has been tried, and has given unsatisfactory results. Messrs. Wilson and Sons, of Hull, have taken a lead in this matter, and by the courtesy of Mr. Charles Wilson, M.P., Mr. Hide, M. Inst. C.E. (the marine superintendent), has furnished details of their experience, extending from 1893. Ten ships have been fitted with water-tube boilers; nine being of the Babcock and Wilcox type. Mr. Wilson has stated in Parliament that there is a sensible saving in weight and increase in carrying-power. In one small vessel he put this at 50 tons; she made fifty trips to and from the Continent each year, and so could carry 5,000 tons more cargo per annum. The conclusions reached by Mr. Hide are briefly as follows:—Under the conditions of their service, frequent thorough examination of the boilers is practically impossible, the stay in port being short. In the earlier installations the boilers

were not made so large in proportion to their work as subsequently. The construction was lighter; they were very hard-worked, and corrosion gave trouble. The cost of upkeep was greater than with cylindrical boilers and the coal-consumption on service greater—probably 25 to 30 per cent. The durability was much less; some of the boilers wearing out in 5 to 6 years, when they were replaced by other water-tube boilers. The quality of coal, and efficiency of stokers, Mr. Hide recognizes to be very different from those in the Royal Navy; and he is of opinion that with better stokers results might be obtained more closely approaching those realized with cylindrical boilers. It may be interesting to add that Mr. Hide is using superheated steam in several vessels of the fleet, one of which has been running for 3 years.

In the United States a considerable number of coasting and lake steamers are fitted with the Babcock and Wilcox boilers, and it is asserted that they give satisfaction. The war-fleet has this type fitted on a very great scale, the aggregate being 375,000 HP. in ships built and building.

The great durability, small cost of upkeep and high efficiency of cylindrical boilers, are, undoubtedly, strong recommendations for their continued use in merchant-ships. They have reached this satisfactory position by many years of gradual development, and not without difficulties on the way, which have been surmounted as experience has been gained. On the other hand, water-tube boilers are in an early stage of development. Competitive types have been multiplied, and with most types very limited experience has been possible. Mr. Milton, who can speak with authority and special knowledge, said here, four years ago, that the water-tube boilers which had been tried up to that date were not suitable boilers, or the best boilers that could be fitted in merchant-ships. But he added that he "believed fully and firmly that a water-tube boiler could be made to give absolute satisfaction in the merchant service." I concur with his opinion, and do not doubt that the result will be achieved, unless the steam-engine itself disappears, as many persons anticipate will happen before long.

Oil-Fuel for Marine Boilers.

There is universal agreement that the advantages of oil-fuel over coal are very great. It appears that experience during the last years practically confirms the conclusions reached by my friend Colonel Soliani (late of the Italian Navy), who thoroughly

investigated the question 10 years ago. Oil-fuel to produce a certain evaporation is 30 per cent. to 35 per cent. less in weight than its equivalent in good steam-coal when both fuels are properly burnt. Special arrangements in the furnaces are required to secure efficient combustion of oil-fuel, and to protect plate-surfaces. With water-tube boilers other modifications are necessary to secure that result; but it can be obtained, according to recent experiments. It may be hoped that ere long the Admiralty will, as in many previous instances, place the results of their investigations before the engineering and shipping communities; more especially as other countries have had larger experience with oil-fuel. There is no need to speak of the saving in labour in the shipment and transport of coal, in stoking, and in the removal of ashes; or the advantages in many other operations of the stokeholds. Taking an Atlantic liner of 40,000 HP., carrying say 3,700 tons of coal, about 2,500 tons of oil should suffice, and 1,200 tons should be added to freight-earning capacity, besides the saving on cost of labour. But it is as true now as it was in 1893, that the questions of adequate supplies of liquid-fuel, and continued reasonable price, have to be settled before its extended use can be contemplated. Those questions remain without a satisfactory answer.

The use of Steel for Ship-building.

Iron gradually gained upon wood, but until about 1870 did not drive it out of the field for merchant-ships, and a little earlier for war-ships. The introduction of mild steel was then imminent. It is singular to notice that the iron used in mercantile ship-building remained practically an untested material, the maker's brand being usually accepted as a sufficient guarantee of quality, supplemented, of course, by the practical test of shaping and working the material in building ships. The Admiralty followed a different course from the first, insisting on tensile and forge tests for all iron plates and bars; for which proof of qualities they had to pay a much higher price. With the advent of mild steel came a complete change in private practice, as, from the first, steel was carefully tested. There was indeed a suspicion of steel, arising from the erratic behaviour of early specimens of that material used for special ships; and it is curious now, with a quarter of a century's knowledge of the greatly superior strength and ductility of mild steel, to remember that it was so distrusted while iron was accepted without question.

The French took the lead in the introduction of mild steel for ship-building; and an eminent naval architect—who was my friend of many years—the late Mr. de Bussy, had much to do with the matter from 1872 onwards. Sir Nathaniel Barnaby at once saw the possibilities of the material, and called on British manufacturers to furnish supplies. The response was prompt. Sir William Siemens undertook the contract at his Landore works, and in 1875 the first two vessels built of mild steel for the Royal Navy—the "Iris" and "Mercury"—were commenced. At first the new material was somewhat dearer than the high quality of tested iron previously used, but it soon became cheaper, and iron almost immediately fell out of use for new war-ships. For merchant-ships the use of mild steel began a little later. In 1877 the Committee of Lloyd's Register sanctioned its use, and in 1879 Messrs. Denny built for the Allan line the first large steel steamer, the "Buenos Ayrean," of 385 feet in length and nearly 4,200 tons. Up to 1891 mild steel was dearer than the untested iron commonly used, and this fact, as well as a lingering doubt as to the trustworthiness of the material, delayed its extensive use. In 1885 only 35 per cent. of the aggregate tonnage built in iron and steel for the mercantile marine was of the latter material. After that date steel gained rapidly, and for the last 10 years it has practically superseded iron for merchant-ships. Iron is now used only for trawlers and small vessels.

Mild steel used for shipbuilding ranges between 26 and 32 tons per square inch in ultimate tensile strength, and its elastic limit (or "yield point") is at 16 to 17 tons per square inch. It is 25 to 30 per cent. stronger than the best quality of iron formerly used in Admiralty practice, and gains even more upon iron such as was used in merchant-ships. In ductility and working qualities it is vastly superior to iron, and operations such as flanging, joggling and bending are now performed on steel in the cold condition, which with iron required to be done hot, or were not practised because of their difficulty and cost. The shipbuilder also commands the supply at moderate cost of plates and bars of dimensions and sections not obtainable with iron, and thus gains in weight in addition to the savings due to superior strength. Increased carrying-power is, of course, the chief reason for using steel, but estimates vary greatly as to the saving in weight in different classes. The universal adoption of steel is ample evidence of its commercial advantage, and experience proves that its superior ductility adds greatly to safety in cases of grounding, collision or other accident. Brunel proved in the "Great Eastern" that, with

well-considered structural arrangements, iron could be used in vessels as large as any yet built. On the other hand, he would have greatly economized in weight had he been able to work with mild steel. In the remarkable developments in dimensions and speeds during the last 20 years, mild steel has played an important part.

At first the liability of steel to corrosion was thought to be greater than that of iron. The Admiralty soon decided to remove the manufacturers' scale in order to lessen this liability, and still continue the practice. In the mercantile marine this is not commonly done. Enlarged experience shows that, with reasonable care in cleaning and painting, the corrosion of steel is not greater than that of iron.

High Tensile Steel.

It is natural that shipbuilders should prefer to adhere as long as possible to so excellent a material as this. Stronger steel has been successfully used, however, in special vessels where economy in weight of hull was of supreme importance. Forty years ago there were examples of this in blockade-runners, and some very notable channel steamers were steel-built long before mild steel was introduced. The materials used were very costly, and great care was needed in working; but, on the whole, the results were satisfactory and some of the lightly-built ships proved very durable. Soon after the "Iris" and "Mercury" were begun, a series of experiments was carried out at the Siemens Steel Co.'s works at Landore, at my suggestion and with the sanction of the Admiralty, to ascertain if stronger steel could be produced with good working qualities. I was charged by Mr. Nathaniel Barnaby with the conduct of these experiments, and they were exhaustive, including tests of the effects of punching and riveting, and the behaviour of representative portions of a ship's structure when subjected to percussion. It was demonstrated then that with open-hearth steel the ultimate tensile strength could be raised to 40 tons per square inch, while maintaining satisfactory ductility and working qualities. Further, that efficient riveted joints could be secured with rivets of the same quality as the plates. In a discussion here in 1882 I summarized the facts. Since that time the production of stronger steel has been facilitated and nickel-alloys have been introduced. Now there is no difficulty in procuring ample supplies if required. Up to the present time little use has been made of it for shipbuilding; but in torpedo-boat destroyers and

small swift vessels it is employed for Admiralty service. About 6 years ago I began to specify such material for certain important portions of the structures of large war-ships—stringers, deck-plating and sheer-strakes. It is found desirable to drill the holes instead of punching them; but no other special treatment is necessary, and excellent results have been obtained in shipyard operations. The gain in strength, measured by the comparative elastic limits, is 20 to 25 per cent. over that of mild steel. Here we have the possibility of substantial savings in weight, on vessels of extreme dimensions or proportions, or of special types. In addition the lesser thickness favours more efficient riveted connections, and drilling tends to excellence of workmanship as compared with punching. It is quite possible that still stronger steel may yet be made available for shipbuilding purposes, and if associated with suitable structural arrangements there is no reason against its employment in some parts, although in the shell-plating great ductility must always be maintained.

Steel Castings.

Large economies of cost and increased rapidity of production have resulted also from the development of mild-steel castings, having low tensile strength and great ductility. These can be readily shaped, in casting, to forms which formerly required expensive bending or machinery and occupied long periods. Anyone who remembers what were the processes and the cost of production for the forged iron ram-stems of ironclads, the stern-posts, the bracket-frames supporting twin-screw shafts, or the rudder-frames of large ships, will better appreciate present possibilities. At first there was some distrust; but 20 years' experience has established confidence. Steel makers, too, when first asked to undertake such castings, were doubtful of the possibility. Their use began when I was at Elswick, and we were to some extent pioneers in this class of work. At the start, Spencer, of Newburn, Jessop, of Sheffield, and the Steel Company of Scotland took an active part, while other makers speedily entered into competition. Now castings which were regarded as impossible are treated as ordinary pieces of work. The shipbuilder has learned how to make the task of the steel-maker easier without undue weight, and the steel-maker has greatly advanced his capability of production. It is obvious that, in view of recent developments in the treatment of steel within critical temperatures, there are good grounds for expecting that steel castings will be still further developed; and

it is satisfactory to know that British metallurgists and manufacturers are alive to this, and are taking a leading part in the preliminary research-work. There is no fear that we have reached the end of the possibilities of steel and its alloys for all classes of engineering work; nor is it likely that steel will give place to other materials for shipbuilding or marine engineering.

Aluminium.

Aluminium has been much talked of for shipbuilding and engineering; trials have been made with it, or its alloys, in yachts, torpedo-boats and small vessels; but, so far, its use is exceedingly limited, and is confined to other than structural work. Pure aluminium has not the strength or qualities required for ships' structures, although it has the great advantage of incorrodibility in sea-water, and relative lightness. Most of the alloys of aluminium and copper which have been tried in shipbuilding have been found to be very liable to corrosion, and to require very careful painting to protect them. The American yacht "Defender," which sailed against the "Valkyrie," was built of this material, and rapidly corroded. In her construction, cost and durability were deliberately sacrificed to increased lightness and sail-power. Mr. Yarrow, with his usual enterprise, has also built vessels of this material; the most notable being a second-class torpedo-boat, constructed in 1894 for the French Navy, 60 feet long and 20½ knots speed, weighing 10 tons complete. These boats had to be lifted and carried by depôt ships, so that lightness was a great advantage. Mr. Yarrow estimated that the weight of hull was reduced one-half as compared with steel, the saving in weight being 2½ tons. This boat also gave serious trouble from corrosion. No doubt the production of alloys of sufficient strength and ductility, which shall be less liable to corrosion, is not beyond the powers of metallurgists. In fact, two years ago I was informed that this was true, and it is possible that experimental verification has been obtained since. It would be interesting if those concerned would give to the Institution information of the actual position of the question, and of the capabilities of existing plant for producing steel plates and bars. For the structures proper I am disposed to think that steel and its alloys will hold their own for some time to come. If cost is subordinated we can now procure material of great strength and little liability to corrosion. Mr. Hadfield has demonstrated this in his valuable monographs on steel alloyed with rarer metals.

At the same time there can be no doubt that, if reasonable cost and suitable dimensions can be secured, aluminium-alloys can be used with great advantage in the parts of ships not contributing in an important degree to the structural strength: such as internal partitions and casings, many fittings, and, above all, in the construction of the towering superstructures which, in modern passenger-steamers, have grown to enormous dimensions, and are carried above the true "strength" deck forming the upper flange of the girder. Large savings of weight are possible in this way; and when made aloft they greatly assist stability. In marine engines also, aluminium-alloys can be advantageously substituted for steel in many parts, especially moving parts. Shipbuilders and engineers will not fail to utilize these advantages if manufacturers can produce suitable materials at acceptable prices. All concerned must see that no possible improvement in the materials of construction is left unutilized.

Scientific Procedure in Shipbuilding.

So long as the types of ships and the mode of propulsion remained practically unchanged, experience continued to be the chief guide in design and construction, and scientific modes of procedure were not extensively used. The science of naval architecture was well established mainly in consequence of the work of great French writers of the Eighteenth Century, and of the encouragement given to the study of the subject by the French Academy of Sciences. In the days when I enjoyed more leisure than for many years past has fallen to my lot, I made a thorough study of the works of the earlier foreign writers, with great advantage, and with the discovery that in regard to questions of buoyancy, stability, and propulsion by sails, small advance in theory had been made since the close of the Eighteenth Century. The "Traité du Navire" of Bouguer, published in 1746, is a work of surpassing excellence. Euler's "Scientia Navalis," published at St. Petersburg not long after, and his "Théorie Complète de la Construction des Vaisseaux," which followed, are worthy of his reputation as a mathematician. Don Juan d'Ulloa gave to Spain a national treatise of great merit. Chapman (an Englishman in origin) did the same for Sweden; and the prize essays submitted by Bernoulli, Euler and others to the French Academy of Sciences, are good examples of original mathematical investigation. Not a few so-called modern discoveries were anticipated in these early treatises, and many remarkable suggestions were made.

The old English books on shipbuilding were produced by men of an entirely different class, most of them practical shipbuilders with only elementary mathematical knowledge. Mungo Murray, who wrote one of the earliest and best, was a working shipwright in Deptford Dockyard to his death—an example of unrewarded merit. The first considerable contribution to the scientific literature of naval architecture made by this country was Atwood's "Disquisition on the Stability of Ships," published 1796–98. When the first school of naval architecture was founded in 1812, Professor Inman chose Chapman's Swedish "Architectura Navalis Mercatoria," and translated it as a text-book for his students. Colonel Beaufoy's classic experiments on resistance to the motion of bodies through water were made under the auspices of the Society for the Improvement of Naval Architecture, founded in 1791, and constituted a valuable contribution to a branch of naval architecture then little understood. Later on, Moseley added a fresh view of stability by his investigation of "Dynamical Stability," and Dr. Woolley, the Principal of the Second School of Naval Architecture, made valuable and original contributions to the geometry of shipbuilding and the methods of calculation required in ship-design. He put on record also, when the Institution of Naval Architects was founded, in 1860, a complete and masterly sketch of the state of the "Theory of Naval Architecture," which is well worth the study of all interested in the subject.

It was fortunate for this country that, when radical changes followed upon the introduction of iron and steam-propulsion, men were available who had been trained under Inman and Woolley for the Admiralty service, and that some had found their way into private employment. Outside the public service there were also some leading shipbuilders and marine engineers fully alive to the value of scientific procedure, including men like Scott Russell, Laird, Napier, Rennie, Penn, and Maudslay. Nor should the services of engineers whose training and principal practice were outside shipbuilding, be forgotten. Brunel throughout was an able exponent of scientific method. William Froude first became interested in naval architecture in consequence of his association with Brunel; and out of his investigations for the "Great Eastern" grew the devotion of a lifetime to work of the highest mathematical and experimental nature, resulting in most important modern developments of the theory of naval architecture. With this original power, Froude associated also a marvellously intimate acquaintance with practice, and interest in progress and

economy. McQuorn Rankine was a worthy co-worker and original investigator in many branches of naval construction. His contributions to thermo-dynamics and the improvement of the steam-engine, his original stream-line theory of fluid-resistance, his investigations of the theory of marine propellers, his systematization of calculations for the strength of ships, are some among the many debts we owe to this gifted man. The great work, "Ship-building: Theoretical and Practical," completed in 1866, in collaboration with eminent naval architects, is of enduring value, and not a few of his generalizations made forty years ago still hold good.

From the nature of the case it is obvious that ship-designing can never be dealt with on first principles solely, or that exact estimates can be made of the most trying conditions to which ships at sea may be subjected. Experience and experiment must always continue to be essential to success. The accumulated results of observations made on the strength, stability and behaviour of ships, and their performances under steam, are of inestimable value. But in making such observations and recording the results, as well as in their subsequent analysis for use in later designs, scientific training and thorough grasp of mathematical principles are essential. In the advance beyond precedent in speeds and dimensions, in the design of new types, and in investigations of critical conditions of strength or stability, the naval architect must base his decisions largely on the collation and comparison of classified facts, drawn from ships that have been thoroughly tested at sea. In fact, he trusts to scientific procedure and not to abstract science.

There is a disposition in some quarters to place the cultivation of pure science on a higher level than applied science. In my judgment, such comparisons are not merely invidious, but of no practical service. Those of us who know by personal experience the keen delight of some new discovery of a purely scientific nature, but whose vocation compels devotion to more practical pursuits, are sometimes disposed to envy our scientific brethren whose lot has fallen in the more serene regions of research in mathematics, physics, chemistry and biology. We appreciate fully their devotion and discoveries, knowing well that all additions to knowledge must benefit mankind, and that many practical advantages will accrue from results obtained independently of special application. On the other hand, we venture to claim for our own work both dignity and value; and to have its difficulties and responsibilities recognized. I well remember days, now long past,

when the working out of some new theorem in stability or resistance gave me the greatest delight; but when, in later days, one had to face the grave responsibility attaching to the decision of the minimum stability permissible, or the form and engine-power necessary to attain unprecedented speed, knowing well that the lives of hundreds of human beings and the wise expenditure of perhaps millions of money were involved, there could not but arise the feeling that one's lot might have fallen in more pleasant places, had fortune favoured devotion to pure rather than to applied science. It may be hoped that controversies of this nature will cease for the future; certainly engineers have no desire to raise them, or to have any but cordial relations with the devotees of pure science.

The change in procedure which has taken place in the designing-offices of private firms during the last 30 years is remarkable. About that period I was preparing a book on "Naval Architecture"; and my endeavour to secure data respecting the experimental results and the qualities of merchant-ships was unsuccessful; chiefly because little information of the kind had been obtained or recorded. There were, of course, some notable exceptions; to their credit be it spoken. Since that time the record and scientific analysis of results, as well as the conduct of experiments, and the thorough investigation of all features in designs, have been greatly developed. Scientific staffs have been created by all the principal private firms, and by the Registration Societies. Lloyd's Register took steps in this direction very early, and has found immense advantage from investigations since conducted by thoroughly educated naval architects, when novel types or structural arrangements have been proposed.

In war-ship work Admiralty practice has been continuously marked by scientific procedure, but here also there has been great advance since 1860. It is but proper to state that the supply of men competent to do the new work, and thoroughly trained as naval architects, has been mainly due, up to the present time, to the enlightened policy of the Admiralty in establishing and maintaining Schools of Naval Architecture. Not merely have they supplied the wants of the public service, but have furnished to the mercantile marine a large proportion of the men holding positions of primary responsibility. The heads of the shipbuilding or designing departments of great private firms, like Fairfield, Elswick, Laird's and Brown's (Clydebank), are men trained by the Admiralty. Our fellow-students trained as marine engineers occupy equally important positions in private business. The

technical staff of Lloyd's Register is largely constituted of men similarly trained, and it was a fellow-student of mine who took a leading part in the radical revision of the Rules for Iron Ships, carried out by the late Mr. Bernard Waymouth, which revision marked a new period of unrivalled usefulness and expansion for that great society. Abroad also Admiralty students have found important positions and maintained the reputation of their class.

There is one department which, in my judgment, has not kept pace with this general advance, by the creation of an adequate scientific staff, of the professional standing and numbers required to perform with full efficiency the very extensive and important duties imposed upon it by legislation. It is a matter to which I would prefer to make no reference, were it not for the serious issues involved in connection with our mercantile marine; but, in the public interest, I will repeat a suggestion made by me twenty years ago, the propriety of which has only been confirmed by lapse of time. I then wrote, "The precedent to be found in the preparation of the (Tonnage) Law of 1854, seems to be a good one. Following after the work of the Commissions, came the careful, extensive and laborious enquiry of Moorsom, a scientific expert, having a thorough acquaintance with the subject and placed in direct communication with the shipping community. If the long-talked-of Central Council or Advisory Board should be constituted to deal with matters relating to the mercantile marine, and if it should be assisted by a competent scientific staff of naval architects, we may hope that, among other much-needed action, will be included the revision of the tonnage laws in a sense that will give more general satisfaction than could otherwise be obtained." No reflection on the present officers and staff of the Marine Department of the Board of Trade is involved in the statement, that twenty years after these words were written they are in my opinion as true as ever. A consultative committee of shipbuilders and engineers has, it is true, been appointed, but it is believed that little or no use is made of it; whereas a similar committee has been of the greatest service to Lloyd's Register. No eminent naval architect, of the same standing as Moorsom was forty years ago, is to be found on the staff. The tonnage law cannot be said to be in a satisfactory state, and the Board of Trade has departed from all tradition, in allowing what are virtually local revisions of the law to be made for the purposes of certain ports, instead of attempting a general revision. There are other important questions affecting the welfare of the mercantile marine which are standing over. If the shipping interests of this country are to be

given their fullest and freest chances of development, some change of the nature suggested is unquestionably required. Foreign competition is increasing, and every possible assistance is needed to our mercantile marine. It may be hoped that this important matter will soon receive the attention it deserves.

British Schools of Naval Architecture.

Allusion has been made to the wise action of the Admiralty in providing systematic training for naval architects. At the suggestion of the Institution of Naval Architects, a third institution, the Royal School of Naval Architecture and Marine Engineering, was established at South Kensington, jointly by the Admiralty and the Science and Art Department, in 1864. In 1873 it was removed to Greenwich, and there continues to this day. I was its senior student, and, in common with all who passed through the course, have reason for gratitude at the excellence of the training given. Three years after my course was finished I became Professor of Naval Architecture, and remained in that position, in addition to my Admiralty appointment, until 1881. It is impossible for me, therefore, to speak impartially of my old school: and it need only be said that its graduates now occupy leading positions in the ranks of naval architects and marine engineers throughout the world. There have been unfortunately comparatively few British students from private firms, but large numbers of foreign students have been trained. Amongst my old pupils are the Chief Constructor of the United States Navy, the Director of Naval Construction of the Danish Navy, and naval architects holding high rank in the Italian and Russian Navies, while two of the three professors of naval architecture at Glasgow University and the professor at the University of Tokio were also in my classes. The school has qualified itself by good work done, and in the present discussions of systems of technical education much may be learnt, I think, from the forty years' experience it can furnish.

For twenty years the School of Naval Architecture stood alone in this country; then by the munificence of Mrs. Elder a professorship of naval architecture was established at Glasgow, Dr. Elgar being its first occupant. Since then classes in naval architecture have been established at the Newcastle College of Science; but, to my regret, no separate professorship of naval architecture exists, and the north-east coast should see to it that this condition of affairs is soon ended.

The University of Liverpool also ought to have its professorship of naval architecture. I took personal action to secure this end in 1894, and was cordially supported by Mr. Ismay, Messrs. Laird and others. Unfortunately, illness prevented me from going on with the movement, and it dropped. It is not creditable to this great shipbuilding country that there should be at Charlottenburg, three or four times as many advanced students of naval architecture as there are in all our colleges.

Lines of Advance in Scientific Procedure.

It is impossible even to indicate all the main lines of advance in scientific procedure which have occurred since 1860. A few may be mentioned.

Investigations of stability are now the rule for war-ships, and are very generally made for merchant-ships. Calculations for stability are made in connection with designs, and experimental determinations of the position of the centre of gravity follow when ships are completed. This was only occasionally done for war-ships prior to the loss of the "Captain" in 1870, and rarely if ever done for merchant-ships for some years after. The mass of data already accumulated is enormous, and the assurance of safety at sea is much greater. Some types of war-ships and merchant-ships would never have been built, and serious accidents would have been avoided in the past, had similar investigations been made. With the need for these calculations has come the device of integrating-machines that greatly economize labour and facilitate work.

Load-line legislation for merchant-ships has been based on careful consideration, by a strong and representative committee, in 1884, of experience gained with ships of various classes. A scientific analysis of that experience was made to determine the effects of heights of decks above water (freeboard), deck-erections and varying "reserves of buoyancy," including a review of strength and stability. Naturally, such a thorny subject did not permit of a solution that commanded universal approval; commercial as well as scientific considerations are involved. On the whole, the settlement seems to be satisfactory, so far as British ships are concerned, although British shipowners naturally desire that in our ports foreign ships should not be permitted to load more deeply than similar British ships. Action by the Board of Trade in this direction ought not to be delayed. Foreign ships are

permitted an unfair advantage in competition from our own ports.

The work of the Bulkhead Committee of 1891 furnishes another illustration of the application of scientific principles to rules for general guidance; in this instance they are not compulsory, but have had wide-spread and beneficial effects on the strength and safety of ships.

Behaviour at sea has been much more thoroughly observed since William Froude dealt with the subject in a novel and masterly fashion forty years ago. The conclusions he then reached furnished two rules for guidance in practice, which rules have been most thoroughly established by subsequent experience. First, that as the period of oscillation of ships in still water is lengthened, the average steadiness at sea is increased. Second, that steadiness may be greatly increased by fitting bilge-keels or other means of increasing water-resistance to rolling. The first rule had been laid down a century before by mathematicians, but had not been supported by such complete reasoning as that adduced by Froude, or by observations of the behaviour of ships. The second was, for a time, disputed. In war-fleets, observations of behaviour have been systematically made for many years past, and these, as well as special experiments, conclusively settle the matter. In the mercantile marine there has been large confirmatory experience. Probably the most notable examples of steadiness at present afloat are to be found amongst the large cargo- and passenger-steamers of the intermediate type, where "stiffness" is very moderate, and the period of oscillation exceptionally long.

Structural Strength of Ships.

The structural strength of ships has been made the subject of scientific investigation since iron came into use, and possibilities of new arrangements or combinations have arisen. Bridge- and girder-construction naturally have had great influence upon the provision of longitudinal strength in ships, and the work of Brunel and Fairbairn led to new departures. Fairbairn is credited with the original comparison of a ship to a girder: but there can be no doubt that Brunel independently worked on the same lines, and his recorded notes on the structures of the "Great Western," "Great Britain" and "Great Eastern," show clearly his recognition of the governing principles of structural strength. So far as these are concerned, there has been no con-

siderable advance, but their application was then the exception, and is now general.

Rankine put into the final shape "equivalent girder" calculations for the longitudinal strength of ships, and did much to give precision and clearness to the conditions governing transverse and local strength. Since his day many other workers have added useful contributions, especially in regard to details of investigation; and a large amount of information has been accumulated as to the actual and comparative strengths of ships. Perhaps the most valuable information has been that obtained from ships which have shown signs of weakness, when the attendant circumstances have been ascertained, and the facts intelligently studied. One can work back from cases of partial failure to an approximate estimate of the straining-forces that must have been in operation. But it is obviously impossible to forecast what is the worst that can happen to a ship at sea, or what are the maximum stresses to which individual parts of the structure may be subjected. Besides resisting the effects of unequal and rapidly varying distribution of weight and buoyancy, the ship must have strength to resist the dynamic effects of rolling- and pitching-motions, the pressure or blows of the sea, the strains due to propelling-apparatus, and the strains produced by load of cargo, armour or armament. These forces produce stresses varying from instant to instant in character and intensity; and any portion of the structure may be subjected to rapidly alternating stresses. Under these circumstances only comparative results can be obtained, and the best basis for deciding scantlings is to be found in trustworthy data for ships that have proved successful or have failed partially. Rankine proposed a procedure for these comparisons, in regard to estimates of longitudinal strength, which still maintains itself in general use. The ship is supposed to float in either of two extreme positions, amongst waves of her own length and of maximum steepness; viz., with her middle on a wave crest, or in the centre of the hollow. For the moment she is supposed to be in hydrostatic equilibrium, and the distribution of weight and buoyancy being ascertained, the shearing-forces and bending-moments can be calculated. This method has given good results in practice, although it is confessedly empirical. When a large step in dimensions has to be taken it must always be accompanied by a careful consideration of the limits of stress which may be accepted under the hypothetical conditions. These limits vary in ships of different types. In many cases considerations of local strength, or failure

by "buckling," govern the scantlings or greatly influence structural arrangements. Between the extremes of an Atlantic liner 700 feet long and 26,000 tons displacement, and a torpedo-boat 230 feet long and 500 tons displacement, there is a wide range of requirement; but, in both, the naval architect has the necessity for securing the lightest structure which is consistent with the provision of sufficient strength.

The latest step that has been taken in this direction by the Committee appointed by the Admiralty to examine into the strength of destroyers has great interest. A destroyer has been subjected to actual bending-moments approximating to those calculated on the usual hypothesis. For this purpose she was suitably supported in dock, and by means of the stress-indicators devised by Mr. Stromeyer, M. Inst. C.E., the actual stresses at various parts of the structure were determined. It is satisfactory to know that there is reason to hope that at an early date engineers will be placed in possession of the results of this unique experiment. To myself it has a special interest, as we bought indicators some years ago for the purpose of making observations on board ship, but, owing to pressure of other work, the experiments were never carried out until the Committee performed them.

Model Experiments and Progressive Steam Trials.

Possibly the greatest advance made in scientific method is that connected with experimental determinations, initiated by William Froude, of the water-resistance to the motions of ships. There had been numerous experiments on resistance previously, but no practical result of importance had followed. So late as 1868 a Committee of the British Association, including many eminent men of science, recorded the opinion that models could not be employed to determine the resistance of full-sized ships, and recommended towing-experiments on the latter. Froude dissented, and proposed a system of tank-experiments, based on a "law of comparison" between ships and models. This law he had independently established on the basis of Rankine's stream-line theory of resistance. It had been previously laid down by an eminent Frenchman, Mr. Reech, in his course of lectures at the School of Application of the *Génie Maritime*, but the fact was not known here. Moreover, Froude dealt with the question of frictional resistance in an entirely original manner, and on this depended the practical utility of the system. Everyone knows that com-

plete success was attained, and demonstrated by the towing experiments authorized by the Admiralty on H.M.S. "Greyhound." From that time onwards, a problem previously insoluble has been rendered easy of solution. Estimates of power for speed have been made more certain, and the naval architect has been able to proceed with greater confidence in attempting unprecedented speeds, and in selecting the forms best adapted to the conditions of any design. After thirty years' experience in the Admiralty the system is in use not merely by some of the leading private ship-builders in this country, but by the naval authorities in France, Italy, Germany, Russia, Holland and the United States. So far it has been applied almost entirely to experiments on ship models and model propellers; but it gives facilities for research on many obscure problems in hydro-dynamics, and it may be hoped that it will be so applied in connection with the National Physical Laboratory or the engineering departments of our Universities. At the technical High School at Charlottenburg an experimental tank has already been established.

Progressive steam trials form a necessary complement to model-experiments on resistance, since the relation of the effective horse-power of models to the indicated horse-power of ships varies in different cases; and unless that relation has been ascertained, model-experiments could not furnish a close approximation to the engine-power required in a new design. Even apart from such steam-trials, model-experiments would, of course, be of great value in enabling the resistances of alternative forms to be compared, and the best combination of form, stability, draught and economical propulsion in any case to be effected. The naval architect has not to seek for a theoretical form of least resistance, but to discover the form which fulfils all the conditions laid down for any design, and gives the minimum resistance compatible with those conditions. He has to keep in view for all ships not merely resistance in smooth water, but the maintenance of speed at sea, and good behaviour. Further, in war-ships, considerations of manœuvring-power, protection and armament, may compel him to accept a greater resistance and larger engine-power, as a factor in minimizing size and cost. These are but illustrations of a general principle; alternatives must be compared before the best selection can be made, and here tank-experiments are of unequalled value.

Apart from model-experiments, progressive steam-trials of ships, properly conducted and recorded, furnish valuable assistance in steamship design. Analysed scientifically, the results for any ship enable close approximations to be made to the performances of

other ships of similar form, but of different dimensions and speeds. Froude's law of comparison is the basis of all these investigations, and in competent hands they yield good results. Questions of screw efficiency are, in fact, best dealt with by progressive trials; for although model-experiments on screws have given valuable information on many matters of principle, they cannot be trusted as yet for the certain selection of the propellers most suitable for any case. Probably, as comparisons between models and full-size screws are multiplied, better results may be obtained.

Screw-Propellers.

After sixty years' experience with screw-propellers it must be frankly admitted that we have very much to learn. The theory of their action has engaged the attention of many eminent mathematicians in this country and abroad. Very many experiments have been made on various ships fitted with propellers of different dimensions and patterns, and in some instances remarkable economies of power or gains in speed have been obtained. Model experiments on screws have been carried out on an extensive scale, and very interesting results have been obtained. Certain general principles have been established, and many problems at first obscure have been solved. But in spite of the theoretical researches of Rankine, William Froude, and many other eminent men, and the experimental investigations of the two Froudes, Thornycroft, Yarrow, Blechynden, Parsons and others, we have not yet established rules by which the selection of the most suitable propeller for novel types or exceptional speeds can be ensured. In some quarters there is a disposition to assert that this result is discreditable to naval architects and marine engineers, who are supposed to have advanced little, if at all, beyond the knowledge possessed by their predecessors forty years ago. These adverse criticisms ignore much valuable work that has been done, with consequent additions to knowledge; and they fail to recognize the inherent difficulties of the problem. Propeller-efficiency depends upon so many variable conditions—not merely in the dimensions, form, pitch-ratio, blade-area, rate of revolution and water-resistance to rotation, but in the movement of the water in which the screw works as affected by the form and frictional wake of the ship—that there must be a vast number of cases to be dealt with, and no general solution may be attainable. When all care has been taken and the fullest use made of available data, success

is not assured in the choice of propellers when precedent is largely departed from. On the other hand, in most, if not nearly all, cases, success is eventually achieved, as the result of experimental trials: although there is often a possibility that even better results might be attained if the trials were extended. This is true of all classes and sizes of ships, from the great Atlantic liner down to the torpedo-boat. No more remarkable record of perseverance and ultimate success in facing difficulties of this nature is to be found than that of Mr. Parsons' work on the "Turbinia" six years ago; yet, in May last, further trials made with three propellers, instead of nine previously fitted, showed a marked improvement in speed for a specified power. Thornycroft, Yarrow, and other builders of torpedo-craft, could tell a similar tale, and so could many builders of swift merchant-steamers. As details of the trials of His Majesty's ships are always published, and naturally awaken interest—especially when difficulties temporarily exist in obtaining estimated speeds—there is sometimes a tendency to suppose that, in Admiralty practice, troubles with screw-propellers are unusually numerous. This is not true; but it is correct to say that in such cases the Admiralty have given to the engineering profession the fullest information of the trials and of the results, in order to assist future practice. The case of the "Iris" in 1878 is one notable example. She was a twin-screw cruiser of exceptional speed. Recently there have been other notable examples, in the "County" and "Drake" classes of armoured cruisers, for which I guaranteed the high maximum speed of 23 knots, anticipating that it would be exceeded. A few details may be of interest.

The "Drake" class attained or exceeded this speed on trial. There was reason to believe, however, from the progressive trials, that an increase in blade-area was desirable. The original screws were 19 feet in diameter, 24½ feet pitch, and each screw had 76 square feet of blade-area. With 116 revolutions per minute and 30,860 HP. a speed of 23·05 knots was reached. The new screws were of the same diameter, pitch 23 feet and blade-area 105 square feet. With 122·4 revolutions and 31,450 HP. a speed of 24·11 knots was attained—a gain of fully 1 knot in speed. From the progressive trials it was found that with 116 revolutions and 26,000 HP. the new screws gave a speed of 23 knots, or a saving of 4,860 HP., as compared with the first screws.

The trials of the "County" class were no less interesting. The earlier trials were made with screws 16 feet 3 inches in diameter, 20 feet pitch, and 54 square feet of blade-area. With 147 revo-

lutions and 22,500 HP. the speed attained was 22·7 knots, or three-tenths of a knot less than the estimate. The progressive trials again showed excessive slip at the higher speeds, and indicated insufficient blade-area. New screws had been ordered before these trials were undertaken, as I considered from other trials that the blade-area would probably prove too small. Further trials were made with screws having 50 per cent. greater blade-area, the diameter being unchanged and the pitch decreased by 6 inches only. With 140 revolutions and 22,700 HP. a speed of 23·6 knots was attained. On the latter trials the speed of 21·64 knots was attained with 16,500 HP. for 30 hours' continuous steaming; previously, with the original screws, 20·5 knots was realized. It may be added, that the original screws for all these cruisers were designed after full consideration of the results of model-experiments with screws, and of experience up to date with the propellers of swift cruisers. The altered conditions in the new designs, however, made this large increase in blade-area necessary, although at the time when the dimensions were settled no one concerned anticipated such a necessity. Obviously it is very difficult on model screws of small size to represent correctly the conditions of water-resistance to rotation and of effective thrust on full-size propellers. Possibly the conditions of the "wake" of the model ship may also differ in some respects. The subject is one calling for extended experiment and analysis. From what has been said, however, it is obvious that great practical advantages and possible economies may be gained by progressive trials made on individual ships with different propellers. In this direction something has already been done, and it deserves further consideration from naval architects and marine engineers.

Vibration of Steamships.

Finally, on this matter of scientific procedure, reference may be made to investigations of the vibration of steamships, and the balancing of reciprocating-engines. Formerly vibration was regarded almost as a necessary evil at certain rates of revolution, and it was considered sufficient to avoid those rates if possible. Marine engineers gave little attention to balancing the moving parts of machinery, or to removing the causes producing vibration. As the powers and speeds of steamships increased, the effects of vibration became more serious. The subject has now been taken up and dealt with in a scientific manner, with most

beneficial results as regards the efficiency of the machinery, the reduction of vibratory movements in the hull, and the comfort of passengers and crews. Incidentally, a mass of information has been obtained, by means of special instruments, as to the extent, periods and character of the actual vibratory movements in the structures of ships, the best means of distributing material in order to reduce the effects of vibration, and the influence of screw-propellers on vibration. It can hardly be credited that only a few years ago the designers of marine engines took no such precautions as are now commonly taken to minimize the forces producing vibration; while shipbuilders regarded vibration as a necessary evil, and, not infrequently, wasted money and material in futile endeavours to strengthen or stiffen structures, and to "kill down" vibration. One incidental advantage of using turbine machinery is, of course, freedom from vibration: and if this system comes into more general use, the systems of balancing, which have been worked out in a thoroughly scientific fashion, will no longer be required. But the principle which it illustrates will continue to be operative and important—the marine engineer and the naval architect must never proceed in their individual capacity, in disregard of the influence of the work of one upon that of the other.

Relation of Naval Architecture to Engineering.

The marine engineer and the naval architect are so closely associated in their work that it is no easy matter to define a line of demarcation between their respective tasks. In fact it is essential to success that their action shall be harmonious and united. The marine engineer is responsible for the design and manufacture of the propelling-apparatus; the details of the machinery and boilers are left entirely to him. The credit of economies in weight, space, and coal-consumption belong to him. His requirements exercise considerable influence on the internal arrangements of ships, the appropriation of spaces to be occupied by machinery, boilers and fuel, their subdivision, ventilation and means of communication, and the structural arrangements necessary to resist local stresses incidental to propulsion. On the other hand, the conditions of accommodation and cargo-stowage in merchant-ships, or the demands made by armament and protection in war-ships, necessarily govern to a large extent the approximation made to the conditions which the marine engineer would prefer if absolutely free. It has been urged that, in war-ships especially, conditions have

been imposed on the marine engineer which seriously affected efficiency and endurance of the propelling-apparatus; but these statements usually proceed from imperfect knowledge of the facts. Naval architects do not desire to impose unfair conditions, and marine engineers are not disposed to accept them. Both have their special difficulties to surmount, and experience has convinced them that their respective tasks are made easier by mutual assistance and consideration. In this country it is usual to specialize in practice, either in shipbuilding or in marine engineering; but it is well understood that the future naval architect should, in his training, embody a considerable acquaintance with marine engineering, while the marine engineer should be familiar with the salient features of shipbuilding. As a naval architect I gladly bear testimony to the loyalty and skill of our professional colleagues, with whom my personal relations have always been most cordial.

Shipbuilders owe much of their success also to the assistance and collaboration of the metallurgist, the steel maker, the mechanical engineer, and (in later days) the electrical engineer. In the course of these remarks I have endeavoured to express our sense of obligation to all our professional brethren. The naval architect has to work with all, and to arrange in each design for the best possible combination of the conflicting requirements of each in the finished ship. He is the connecting-link—or perhaps one might say the more or less "elastic buffer"—between all who contribute to make up that wonderful product—a modern steamship.

Nor is the shipbuilder dissociated from engineers engaged on works of construction. Indeed, in the matter of harbours and docks the two classes are painfully conscious of each other's existence and work. The growth in size and power which has been traced in this Address, has made obsolete, in short periods, provisions in harbours and docks which, not long ago, seemed ample. And as I have pointed out, as the demand for still higher speeds is made, so does the rate of increase in dimensions augment. At the International Maritime Congress held in this hall ten years ago I was the mouth-piece for a message from the Shipbuilding section to the Harbours and Docks section, asking for deeper water, broader entrances and greater lengths. The cry has since become more bitter from us, and the response from dock and harbour authorities, although favourable on the whole, is accompanied by an undertone of complaint, because ships continue to grow so rapidly. As investors, we naturally sympathize with this feeling;

as shipbuilders, we must sternly demand absolute freedom to fulfil the conditions arising from commercial or warlike requirements. A few weeks ago I traversed the Liverpool Docks, and saw in progress great works for deepening and reconstruction. Such works are proceeding in all great ports: or new docks and quays are being constructed.

By the favour of professional friends, who are responsible for those works at Liverpool, Avonmouth, Southampton, Bombay and other ports, I know what is contemplated, and have advised the provision of the utmost possible margin for extensions over present requirements, especially in depth of water and breadth of entrances. I cannot go into details, but may say that it seems to be accepted now that a first-class port should have provision for ships up to 1,000 feet in length, with 100 feet in breadth at entrances, and 33 to 35 feet depth of water. Depth of water, as I have explained already, is a crying need for economical ship-construction and propulsion; lengths and breadths have been extended far beyond the proportions in which the draughts of ships have been increased, and this involves unfavourable conditions for speed and dead-weight capacity. At our great ports the necessity is now recognized, and provision is being made for greater depths of water.

The approach-channel through the Mersey, including the bar, has 26 feet depth of water at low-tide. The Liverpool Docks have entrances 100 feet wide and depths over the sills of about 33 feet at high-water of ordinary spring-tides. Vessels up to 900 feet in length can be accommodated in floating- and graving-docks. At Southampton the existing entrance-channel is 30 feet deep at low-water of ordinary spring-tides, and powers have been obtained to increase it to 35 feet. At the quays the corresponding depths are 28 feet to 30 feet, and these can be increased. At high-water 13 feet greater depth is available; and for nearly three hours the depth is maintained almost constant owing to singular local conditions. Graving-docks at this port will receive vessels 750 feet to 850 feet in length, and 85 feet to 88 feet in width, the depths over blocks being 32 feet to 33 feet at high-water of ordinary spring-tides. The Avonmouth Docks now under construction will have entrances 100 feet wide and locks 850 feet long, and the depth of water will be 36 feet at high-water of ordinary neap-tides and 46 feet at high-water of ordinary spring-tides. Corresponding graving-dock accommodation is to be provided. For the Thames the Royal Commission recommended, and the Port of London Bill provides for, a navigable channel up to the Royal Albert Docks having 30 feet of water at low-water of ordinary spring-tides. At Greenock the docks have 32 feet

to 35 feet of water on the sills. The great works done on improvement of the Clyde now require extensions to meet modern conditions. Recently leading shipbuilders and shipowners have pressed for the necessary improvements in depths of water and form of channel to suit the larger ships. It has been stated, apparently with truth, that some of the most famous shipyards on the Clyde cannot take orders for ships that are contemplated because of difficulties in launching and navigation to the sea. It is certain that this need will be met; there is no lack of enterprise in that region. The Tyne is better off. No practical limitation has yet been imposed by the conditions of the river to the dimensions of ships built on its banks or trading to the port. On the bar there is 25 feet of water at low-water of ordinary spring-tides, and the rise at neap-tides is 11½ feet.

Abroad, in the great ports, similar provision has been made or is contemplated. At Antwerp vessels drawing 28 feet to 30 feet of water can lie alongside the quays. At Bremerhaven the entrances are about 88 feet wide, and the depth of water is about 34 feet at high-water of ordinary spring-tides. Hamburg uses Cuxhaven as its port for large vessels, the tidal harbour having a depth of 26 feet at low-water of ordinary tides, with a rise of 9 feet. Vessels of about 24 feet draught can proceed to Hamburg at normal tides, and the deepening of the channel is certain. New York has a great scheme for 40 feet of water in the approach-channel, but under present conditions it appears that the deepest departure-draught permissible is about 32½ feet, and it is most desirable that the contemplated works should be completed in view of the increased dimensions and speeds of ships. At Bombay the proposed entrances to the docks are 750 feet long, and 90 feet wide, with 37¼ feet depth of water on the sills at high-water of ordinary spring-tides.

As an illustration of what advantages result from increased draught in a great Trans-Atlantic liner, reference may be made to the "Deutschland." Like all the swiftest mail-steamers she carries very little freight, because of the limits imposed by her departure-draught. It has been stated, and is probably correct, that this great ship of over 23,000 tons displacement can carry only 500 tons to 600 tons of cargo. If her draught could be increased 1 foot, about 950 tons more cargo could be carried, and 2 feet increase would represent about 1,800 tons more cargo. The freight-earning capacity would thus be nearly trebled for 1 foot extra draught, or made five-fold for 2 feet, with a very trifling loss of speed even at the deeper draught.

The Suez Canal restricted the draught of ships passing through it to 24 feet 6 inches up to 1890, and at present the limit is

understood to be about 26 feet 3 inches (8 metres). This increase in draught has been obtained as the result of strenuous representations made by British shipowners. Sir Charles Hartley has told the story in his admirable Paper[1] published in the Proceedings for 1900. It is there stated that the deepening is to be carried to 9·5 metres, permitting ships to draw 29 feet to 29½ feet. This is an enormous advantage. I illustrated what it meant at the British Association Meetings of 1899, and will now add a few figures. The "Moldavia," of the Peninsular and Oriental line, began her service recently. On a draught of 27 feet 4½ inches she carries about 3,000 tons of cargo. Each additional foot of draught gives an increased carrying-power of about 650 tons. Three feet increase would therefore add about 2,000 tons—66 per cent.—to her freight-earning capacity. There would be some decrease in speed, but nothing sensibly affecting her time on passage. Facts such as these explain the insistence of shipbuilders and shipowners in urging the necessity for greater depths.

The North Sea Canal and the Amsterdam Ship-Canal have been deepened to nearly 30 feet. The Manchester Ship-Canal has a depth of 26 feet, with provision for deepening to 28 feet, and it may be anticipated that this work will not be long deferred.

In this Institution we are accustomed to deal with difficult engineering problems. Naval architects claim no monopoly of difficulty or responsibility. Their work presents certain special features, however, and these I cannot express better than in a few sentences contained in an address given at Liverpool ten years ago, when endeavouring to enlist support for the establishment of a Chair of Naval Architecture in the University.

"The problems arising in the designing, construction, and propulsion of ships are very various and complex. In all cases it is required to produce a structure which shall be strong, stable, and seaworthy; capable of transporting safely across the stormy sea precious loads of human lives or merchandise; and to endow the structure with the means of propulsion. It is impossible to forecast with any certainty what will be the most trying conditions to which this structure may be subjected; what buffets it may receive from the angry waves; what risks it may encounter of being overwhelmed by the sea; what extremes of oscillation may be impressed upon it; what stress of wind and weather it may have to sustain.

[1] "A Short History of the Engineering Works of the Suez Canal," by Sir Charles Hartley, K.C.M.G., M. Inst. C.E. Minutes of Proceedings, Inst. C.E., vol. cxli. p. 157.

"The civil architect and engineer have many most difficult tasks to perform; but, in the last resort, they have always the solid earth to found upon. It may not be easy to secure a trustworthy foundation in some cases, and much skill in design, as well as enormous outlay in money and material, may be necessary to reach this essential result; but it is always within the range of possibility. The naval architect, on the other hand, has constantly to keep in view the fact that the structures he designs are to float and carry loads. Economy of weight in structure is, therefore, of paramount importance, since it results in increased carrying power; and there is an inevitable pressure towards that selection of materials and structural arrangements which best favours the association of lightness with strength.

"The grandest triumphs of civil engineering and civil architecture have this distinctive feature as compared with ships—they are immobile. Consequently it is possible to determine with fair approximation the extreme conditions for which strength should be provided in the design, and to provide a reasonable margin. Great scientific knowledge and technical skill are requisite, no doubt, to successful achievement, even under these conditions. One gazes with admiration and respect upon a grand cathedral, or a mighty structure like the Forth Bridge. But if the spectator is a shipbuilder, his admiration is mixed with envy at the greater certainty and larger possibilities inherent in immobility, and a foundation which can be assured if the price is paid.

"A ship at sea offers a complete contrast to the conditions holding good in land structures. In onward motion herself, she is surrounded by waves in rapid motion, and very frequently is subjected to violent oscillations of rolling and pitching. Her structure has to be adapted for carrying heavy loads, sustaining the propelling apparatus, and resisting the pressure or blows of the sea. It must be capable of withstanding bending and racking moments, which tend to alter its form longitudinally and transversely. From instant to instant these forces are changing in character and intensity, and the maximum stresses on the structure are not merely varying in amount, but changing rapidly from tensile to compressive at any selected portion of the structure. Exact determination of the maximum values of these stresses is impossible, because the worst combination of circumstances cannot be predicated. In short, the naval constructor has necessarily to face the unknown and unforeseen in much of his work, and if he succeeds in his attempt cannot be sure of the margin of strength he has provided."

Merchant Shipping in 1903.

Attention must now be given to the present conditions of British shipping and ship-building, as contrasted with the conditions sketched for 1860. Here I must venture on a few statistics drawn from the valuable Tables issued by the Board of Trade and Lloyd's Register of Shipping.

Since 1860 the tonnage shown on the Register of Shipping for the United Kingdom has been increased about two and a half times. At the end of 1902 the lists showed 9,152 vessels, of about 14,900,000 tons (gross). British possessions owned 1,982 vessels, of 1,117,000 tons. The total for the Empire was 11,134 vessels, aggregating over 16 million tons. All other maritime countries combined owned 18,809 ships, with an aggregate tonnage of about 17,637,000 tons. The United States owned 3,386 vessels, of 3,612,000 tons, of which 405 vessels, aggregating 1,130,000 tons, were for Lake service. The German Empire owned 1,898 vessels, of 3,283,000 tons, of which about 80 per cent. belonged to the two great ports of Hamburg and Bremen. Norway and France each owned about 1,600,000 tons, and Italy nearly 1,200,000 tons.

Under modern conditions steamships are reckoned, for commercial purposes, to be equal to four or five times their tonnage in sailing-ships. It is interesting, therefore, to compare separately the steam tonnages. In 1860 the gross tonnage of steamships on the British Register was about 700,000 tons; in 1902 there were 7,530 steamers, aggregating 13,411,000 tons. British possessions owned 1,023 steamers, of 783,000 tons. The total for the Empire was 8,553 steamers, of 14,193,000 tons. All other maritime countries combined owned 9,228 steamers, of less than 13 million tons. The United States possessed 1,211 steamers, of 2,222,000 tons, of which 349 steamers, of 1 million tons, were for Lake service. The German Empire owned 1,425 steamers, of nearly 2,800,000 tons. France had 717 steamers, of 1,154,000 tons, and Norway 962 steamers, of 935,000 tons.

In 1860, 90 per cent. of the British mercantile tonnage was in sailing-ships; in 1903, 90 per cent. is in steamers. In this period British sailing tonnage has decreased by more than two million tons, while steam tonnage has increased by more than 12½ million tons. Sailing-ships are still built, in comparatively small numbers. In 1902, in the United Kingdom, 72 vessels, of nearly 50,000 tons, were launched. Abroad, and especially in France, under the

bounty system, many sailing-ships have been built, some of very large size. In 1902, 55 French iron and steel sailing-vessels, of more than 140,000 tons, were launched; and outside the United Kingdom 469 sailing-ships, of 327,000 tons, were built. The average tonnage per ship was small. Steamers are now competing successfully with sailing-ships on the longest voyages, and nearly monopolizing the coasting trade. Sail-equipments in steamers have been diminished practically to "steadying-sail," as against the "full-spreads" usual in 1860. In 1902, 96·7 per cent. of the new tonnage built in this country was in steamers.

The British Register for 1902 only included 102 wood-built steamers, of 16,000 tons, and 613 sailing-ships, of nearly 107,000 tons. Iron gained very rapidly on wood after 1860, and about 1870 it became supreme. Having vanquished wood, it has had to give place to mild steel. Since 1890 iron has practically ceased to be used, except for trawlers and small vessels. In 1902, 99·8 per cent. of the new tonnage launched in the United Kingdom was of steel. The Register shows that, at the close of the year, there were 2,384 iron steamers, of 1,120,000 tons, as against 5,037 steel steamers, of nearly 11½ million tons. That is to say, nearly 86 per cent. of our steam-tonnage is now of steel, with all the consequent advantages of lightness, strength, and greater carrying-power. One striking feature of our modern mercantile marine is the determination of ship-owners to keep abreast of requirements and to maintain efficiency by substituting new for old ships. Last year, for example, sales were made of 273,000 tons of steamers, and 46,000 tons of sailing-ships belonging to our mercantile marine, as against purchases of 85,000 tons from foreign and colonial owners. On the other hand, new ships were added, aggregating over 1,121,000 tons in steamers, and less than 35,000 tons in sailing-ships. The British steam-tonnage was increased by 788,000 tons of ships having the latest improvements in hulls, engines, and equipment, and the sailing-tonnage was diminished by 44,000 tons. These are representative changes, indicating clearly that British shipowners intend to maintain their lead in the trade of the world.

Our position in shipbuilding is no less remarkable. Last year in the United Kingdom there were launched 622 merchant steam-ships, of 1,378,000 tons, and 72 sailing-ships, of over 49,000 tons, while 23 war-ships, of over 94,000 tons displacement, were set afloat. Taking the seven years 1896–1902, the average annual output has closely approached 1,330,000 tons, which closely approaches the total tonnage of shipping owned by France and

Norway and exceeds that of Italy. It is more than half the total American tonnage for sea-service, and equals 40 per cent. of the total tonnage owned by Germany. Shipbuilders no less than ship-owners are keen to maintain supremacy, and so long as this spirit prevails, and we are not above learning from other countries any useful lessons they can teach, our position will be secure. Much is said of the growth of foreign shipbuilding, and it is unquestionable that great strides have been made in recent years by the United States and Germany, while it may be anticipated that they will go further. Still it is reassuring to find that in 1902 the total output of shipbuilding in all countries outside the British Empire amounted to 967 ships, of 1,237,000 tons, to which the United States contributed 265 ships, of less than 400,000 tons; Germany 121 ships, of 258,000 tons; and France 113 ships, of 237,000 tons.

We hold our own, too, in economy of first cost and in speed of construction. As to first cost, one remark may be made. It has been alleged recently that the first cost of British-built ships has been sensibly diminished by the importation from abroad of large quantities of forgings, castings and other materials, which were supplied at lower rates than prevailed here, and, in some cases, at less than cost price. German steel-makers are credited with having done much in this direction. It is no doubt a fact that orders for some such materials have been placed in Germany, and it is equally true that not a few of these orders have been so placed in accordance with the desire of German owners of ships being built here. It is admitted, too, that German steel-makers have shown great ability in advancing the manufacture of forgings and castings, and are ready to furnish them at reasonable prices. On the other hand, there have been special circumstances, to which I shall not allude, affecting this branch of British manufacture, which have led shipbuilders to encourage foreign competition for a time. But the essential fact is that these foreign supplies have been relatively limited and unimportant, in proportion to the grand scale of operations in British shipbuilding; they have not sensibly influenced the total costs of production, and an entirely fictitious importance has been attached to them by imperfectly-informed persons. The real sources of our superiority are to be found in the lead we took on the introduction of iron and steam-ships, the consequent advantages resulting from the training of two generations of skilled workers, and the enterprise shown by shipowners and shipbuilders. Other nations will and should develop as time passes; we have the unalienable advantages of

greater experience and immensely larger manufacturing resources. Unless an entire change in the spirit of all interested in shipping occurs, or the folly should be committed of not utilizing all means of improvement wherever they may originate, we should maintain our lead.

Since 1860, as will be seen from the foregoing figures, there has been a very great increase in the average dimensions and tonnage of ships. This has been due in great measure to increase in speed and in the lengths of voyages undertaken by steamships, but also to the fuller appreciation of the principle that economy of transport and propulsion is favoured by having ships of large dimensions whether they be sailing- or steam-ships. Brunel and others who dealt with these questions half a century ago were fully alive to the advantages of large dimensions. The researches of Froude and Rankine have emphasized the principle, and made the theory underlying that principle clearer and more precise; but experience has been the great teacher, and everyone now realizes the truth. In all classes of ships, growth in dimensions proceeds rapidly, with beneficial results. It may be interesting to illustrate this tendency by giving a few facts for iron and steel steamers. In 1860 the average gross tonnage for steamers exceeding 100 tons was 340 tons; in 1870, 580 tons; in 1880, 1,250 tons; in 1890, 1,570 tons; in 1902, 2,200 tons. This average, it must be noted, includes a large number of yachts, river- and coasting-steamers, and other vessels less than 200 tons. If these were eliminated, the growth in other classes would be shown to be much greater, as in these special vessels the circumstances of their employment impose limits on dimensions.

The most marked advances have taken place in the last 10 years. In the period 1892–5 only 8 vessels per annum were built, on an average, of 6,000 tons or more; in the next four years (1896–9) this average rose to 25; for 1900–2 it was 41. Last year 28 vessels exceeding 7,000 tons were built, nine of them exceeding 10,000 tons. Ten years ago there were few vessels of 10,000 tons. At the end of 1902 there were 84 steel steamers of 10,000 to 20,000 tons; forty-eight of these had been built and thirty-nine were owned in the United Kingdom, twenty-six belonged to Germany and nine to the United States. The other ten were owned in France, Holland and Denmark. At the same date there were 145 vessels whose gross tonnage ranged between 7,000 and 9,999 tons, of which the United Kingdom owned 106, Germany, 22, and the United States, 7 vessels.

The Largest Steamships Afloat.

The three largest merchant-steamers now afloat are the "Cedric" and "Oceanic" of the White Star Line, and the "Kaiser Wilhelm II." of the North German Lloyd. All three approximate to the "Great Eastern" in length, but differ from that ship and between themselves in other dimensions and in many features. They are all employed in Trans-Atlantic service. It will be of interest to compare and contrast them: and to indicate how, nearly half-a-century later than the design of the "Great Eastern," designers have dealt with the problems which Brunel faced before experience with large ships had been gained. In the interval, and step by step, the gap which was made by his courage and skill has been traversed: so that later workers have had better guidance and have taken less risk. By the kindness of the owners and builders of the vessels I have been enabled to make an exact comparison. The principal results shall now be stated.

The "Cedric" is the largest ship afloat. Her length between perpendiculars is the same as the "Great Eastern's" (680 feet): over all she is about 4½ feet longer than her predecessor (697½ feet). Her breadth is 75 feet, as against 83 feet for the "Great Eastern." If depth of water were available she could be laden to 36 or 37 feet, and would then have a displacement of 37,000 tons to 38,000 tons. But under existing conditions at her terminal ports, she does not exceed 32 feet draught and about 32,000 tons displacement. At the same draught, the "Great Eastern" displaced about 30,000 tons. The gross tonnage of the "Cedric"—roughly a measure of her internal capacity—is 21,000 tons, or about 2,000 tons more than that of the "Great Eastern." Her moulded depth to the upper deck is about 48½ feet, or 9½ feet less than the "Great Eastern"; her tonnage under the deck is 17,100 tons, while the corresponding tonnage in her predecessor was about 18,800 tons. The essential difference is that in the "Cedric" large superstructures for passenger-accommodation are built above the structural upper deck, adding nearly 4,000 tons to the capacity; whereas there were only a few small erections above the flush deck of the "Great Eastern." These superstructures, of course, add considerably to the weight of hull, and contribute greatly to the comfort and accommodation of passengers; but they give little assistance to structural strength. Both ships are capable of carrying about 3,000 passengers, besides a large dead-weight. The "Cedric" is propelled by twin-screws, driven by inverted-vertical-cylinder quadruple-expansion engines

developing about 13,000 HP.; her sea-speed is about 16½ knots; the boiler-pressure is 210 lbs. These engines and boilers weigh very little more than those of the "Great Eastern"; but develop fully 60 per cent. more power. For equal speeds the two ships, if fitted with similar propelling-apparatus, would probably require about the same power, but the twin-screws of the "Cedric" are doubtless more efficient as propellers than the screw and paddles of the earlier ship, and are less affected by variations of draught.

The modern ship, with her eight-fold boiler-pressure and higher range of expansion, requires at 16½ knots not more than one-half the coal-consumption of the "Great Eastern" at 13½ knots.

The hull structures are radically different. The "Cedric" has a number of strong steel decks, and a cellular bottom with longitudinal frames extending out to the bilges. Her main framing, however, consists of closely-spaced transverse frames, and her shell-plating is much heavier. After allowing for the weight of superstructures, the structural weight is, in my judgment, much greater than that of the "Great Eastern"; and, at the same draught of water, her dead-weight capacity (coals and cargo) is considerably less. Absolutely it is very large indeed, exceeding 12,500 tons on present service-draught, and being capable of increase to 18,000 or 19,000 tons if depth of water were available. She is a noble specimen of the so-called "intermediate" class of steamer, which has been growing in favour of late, concurrently with the development of swift mail- and passenger-steamers. They stand between the latter and the pure cargo-steamer; hence the designation.

The White Star Company have now building at Messrs. Harland and Wolff's works a still larger vessel, to be named the "Baltic." She will be of the same breadth but nearly 30 feet longer than the "Cedric," about 1,300 tons greater tonnage and 2,000 tons greater displacement, with a proportionate increase in dead-weight capacity. Her speed is to be the same. The "Baltic" at last goes beyond the "Great Eastern" in length between perpendiculars, as well as in displacement and tonnage, but is still inferior in breadth and depth moulded. It is improbable that she will long retain the distinction of being the largest ship.

The "Oceanic" was completed in 1899, and was, until this year, the largest passenger- and mail-steamer afloat. Most of the swift Trans-Atlantic steamers of this class have very small relative dead-weight capacity; the "Oceanic," on the contrary, can carry about 8,000 tons of coal and cargo on her service-draught of 30 feet 6 inches, and, allowing about 3,000 tons for coal, this leaves

5,000 tons for cargo. If she loaded to 32 feet, this would be increased to fully 6,500 tons. Her sea-speed is moderate, according to modern standards, viz., 20¾ knots per hour. Her twin-screw triple-expansion engines develop 26,000 HP., corresponding to a coal-consumption of about 450 tons per day. The steam-pressure is 192 lbs. The length over all is 705 feet, between perpendiculars 685 feet, breadth 68 feet, depth 49 feet, gross tonnage 17,274 tons, under-deck tonnage 14,730 tons. At the service-load draught (30½ feet) her displacement is 26,400 tons or 4,000 tons less than the "Great Eastern" at the same draught. Her finer form, as compared with that ship and the "Cedric," is, of course, essential to the much higher speed. From the naval architect's point of view it is most interesting to note the differences between the "Cedric" and the "Oceanic," belonging as they do to the same owners, designed and built by the same shipbuilders. At the same draught the "Cedric" is of 4,400 tons greater displacement, her engines are of only half the power and her coal-consumption is probably less than one-half that of the "Oceanic." On these two items the "Cedric" gains over 3,000 tons, which, with her greater displacement, means that about 7,500 tons are made available for various purposes at the discretion of owner and builder. As a matter of fact, part of this is applied to increase in dead-weight capacity and part to heavier hull. The "Oceanic" can carry nearly 2,000 passengers, of whom 800 are first and second class. The "Cedric" carries nearly 3,000, of whom 650 are first and second class. Both types find full employment.

The late Mr. Ismay did me the honour of communicating his views as to the design of the "Oceanic," and of consulting me on some points, as he did some years before when the design for the "Teutonic" and "Majestic" was being arranged. It is therefore possible for me to speak from personal knowledge of the reasons which led him to fix the sea-speed at 20½ knots to 21 knots, at a time when the German Steamship Companies were aiming at 22½ knots to 23 knots, and 5 years after the Cunard Company had built two 22-knot steamers, the "Campania" and "Lucania," which still remain the swiftest British Trans-Atlantic steamships. In justice to the memory of a great shipowner, and with the concurrence of Mr. Bruce Ismay, I may state that the moderate speed of the "Oceanic" was decided upon after careful consideration had been given to the question of higher speeds, the increased first costs and greater working expenses, as well as the maximum subventions from the Government which could be looked for at that time. Mr. Ismay came to the conclusion that,

unless larger aid was given by the State, these faster vessels could not be worked at a commercial profit—a conclusion verified since by independent authorities after full inquiry. His view was that the least saving in time on the voyage, that would be of practical value, was 12 hours, and that the additional cost was not justifiable on commercial grounds. It was decided, therefore, to adhere to the lesser speed—about a knot more than the "Teutonic" of 1889—and such a reserve of power was provided as ensured almost absolute regularity on service. This result has been secured. It may be worth adding that I estimate that to have gained this 12 hours would have added about 30 per cent. to the power, nearly 20 per cent. to the coal bill, and reduced the freight-earning capacity by nearly 40 per cent. This indicates the serious aspect to the owners of increased speeds.

The third of these great Atlantic ships is the German "Kaiser Wilhelm II." which began her service in the spring of this year. Her extreme length is 706·5 feet; between perpendiculars 683 feet; nearly the same dimensions as the "Oceanic." Her breadth is 72 feet, depth 52½ feet, gross tonnage 20,000 tons. Her working load-draught is a little over 29 feet, the corresponding displacement being 25,600 tons. Her twin-screw quadruple-expansion engines are arranged in four sets, two on each shaft; this arrangement has been adopted also in the Italian battleships of the "Sardegna" class, and in my design for the cruisers "Blake" and "Blenheim" in 1888. The maximum power developed is 40,000 HP. to 45,000 HP., with 225 lbs. steam-pressure, and the maximum sea-speed is 23 knots. It is probable that some improvement in speed may be realized as the service is prolonged. She is said to carry 775 first-class, 343 second-class and 770 third-class passengers. At full power the coal-consumption must be 650 tons to 700 tons per day, or 200 tons to 250 tons per day more than the "Oceanic"; say 50 per cent. greater expenditure per day. The German ships, it must be noted, have to cover about 200 nautical miles more on the Trans-Atlantic voyage between New York and their nearest European port of call. This involves, roughly, 7 per cent. increase in speed over the "Campania" and "Lucania" if the same length of passage is to be maintained between the terminal ports. It was natural, therefore, that the German designers should think it important to secure speeds of 23 knots to 23½ knots in vessels built to compete with the Cunard ships. They have accomplished this in the "Deutschland" and "Kronprinz Wilhelm," as well as in the "Kaiser Wilhelm II."; but their next step is one of increasing difficulty. If 12 hours are to be gained on the present

ships, the sea-speed of their new ships must be made 25½ knots to 26 knots, with an enormous increase in dimensions, power, first cost and working-expenses. Rumour asserts that the prospect is not regarded as pleasant, but the future alone can show what will be done. Our German professional brethren are not lacking either in courage or resource, nor are they likely to be left without State aid in any task regarded as important to Imperial interests.

STATE SUBSIDIES FOR MAIL STEAMERS.

Until 1898 this country held a commanding lead in speed and size of mail-steamers, owning nearly all the largest and swiftest vessels. In 1887 the Government made arrangements for the subvention, and armament as auxiliary cruisers, of a considerable number of these steamers; and that policy is still operative, although it was announced in the last session of Parliament that it was to be modified. Besides this subvention there are, of course, payments for the conveyance of mails; but the only subsidy under peace conditions, apart from service rendered by conveyance of mails, is that for the Reserve Merchant Cruisers. In the Navy estimates for the current year the total grant under this head is about £78,000, distributed over eighteen ships, and for this small payment the steamship companies not merely undertake to place the subsidized vessels at the service of the nation when required, but also to add thirty-one other vessels, without further subsidy. Having regard to the capital value of this great fleet and the cost of maintenance, the subsidy is obviously very trifling, and constitutes but a modest aid to commercial success. There is good reason for believing that much more substantial assistance is rendered abroad; and that the construction in Germany since 1897 of four Trans-Atlantic steamers, surpassing all British vessels in speed, has been the result, not merely of a desire for commercial advantage, but for the possession of vessels that in time of war would be valuable auxiliaries to their Navy. Action taken here has given the start to this policy, and although opinions differ widely as to the value of these auxiliaries, or the wisdom of contemplating their removal in war-time from their ordinary duties, the facts cannot be ignored that all important maritime countries reckon upon the employment of mercantile steamers of high speed as a part of their naval force. In the Spanish-American war this was done, and the American Atlantic steamers rendered excellent service. The subject is therefore not one to be determined by consideration of

commercial conditions alone, and private shipowners cannot be expected to continue unaided the competition with foreign rivals who receive large encouragement from the State in the production of swift and costly vessels.

What the increase in cost of higher speed in individual ships has been is not generally recognized. In 1874 the "Germanic" and "Britannic" of the White Star Line each cost about £200,000 and averaged 15 knots. The "Germanic" has since had new engines and boilers fitted at a cost of £100,000, and last month made her final voyage between Liverpool and New York. In 1889 an average speed of 20 knots was associated with a cost of £350,000 to £400,000. Five years later the corresponding figures were 22 knots and about £500,000 to £550,000. In 1889 the "Oceanic" cost £700,000. Particulars of the cost of later ships are not available, but the "Mercantile Cruisers Committee" of 1902 after careful enquiry stated that the cost for 23 knots would be £575,000, for 24 knots £850,000, and for 25 knots £1,000,000. My impression is that these estimates are below the actual costs of the "Deutschland" and the "Kaiser Wilhelm II."; probably these ships with 23 knots to 23½ knots speed have involved an expenditure of about £700,000 and £800,000 respectively. While the advance from 15 knots to 20 knots was made for an increase of say 80 per cent. in cost, that from 20 knots to 23½ knots has involved an increase of 100 per cent. to 120 per cent. And the rate of increase must continue to grow as the speeds rise. In steam navigation *c'est le dernier pas qui coûte.* No wonder that the Mercantile Cruisers Committee, with these results before them, concluded that commercial companies would require annual subsidies "towards making good the loss which would be sustained in peace time by running such vessels." They suggested annual subsidies ranging between 2·6 per cent. on first cost of 20-knot vessels and 15 per cent. for 25-knot vessels. For 23-knot vessels the subsidy proposed was 8·6 per cent. The subsidy for 20-knot vessels agreed with that provided for in the Admiralty scheme already in force; but no higher payment than £10,000 per annum was contemplated in that scheme, and vessels of 22 knots speed received that sum, whereas the Committee recommended £40,000.

After full enquiry and consideration of the Report of the Mercantile Cruisers Committee, His Majesty's Government decided that arrangements should be made by which superiority in speed over all existing mail-steamships should once more be possessed by the British mercantile marine. An agreement was made with the Cunard Steamship Company, and executed in July last, by

which that company pledged itself to construct two vessels "capable of maintaining a minimum average ocean speed of from 24 to 25 knots in moderate weather," and to give such proof of that capability being continued each year as may be required by the Admiralty. If the average speed falls below 24½ knots, deductions from the subsidy are to be made. The agreement is to continue for 20 years from the date of the first voyage of the second of the two ships. There are other important conditions, giving the Government powers over the whole Cunard fleet, and providing the funds for the construction of the two new ships. Into these it is not necessary to enter. From the technical side the important facts are: (1) that the minimum average sea-speed in moderate weather is to be 24½ knots; that is to say, 1¼ knot above the speed of the fastest ships now on the Trans-Atlantic service; (2) that His Majesty's Government undertake to advance not more than £2,600,000 at 2¾ per cent. interest, as a loan, to be repaid by annual instalments, each of which shall be equal to one-twentieth of the total amount of the advance; (3) that the annual subvention to the Cunard Company shall be £150,000. This agreement has been sanctioned by Parliament, and its terms have been almost universally approved as being to the advantage of the national defence, and of British shipping interests.

The magnitude and difficulty of the problems involved in the designs of ships required to be 1¼ to 1½ knot faster than any mail-steamer in existence, will be understood from what has been said previously; and there must inevitably be a great increase in size and power. It will be noted that the agreement contemplates a possible expenditure of £1,300,000 on each ship, which is probably £500,000 (over 60 per cent.) more than has yet been spent on any merchant steamer, and equals the cost of our most expensive armoured battleships.

Up to the present time the designs have not been finally arranged, although the matter has been under consideration by the Cunard Company and the leading firms of shipbuilders whom they have consulted. Obviously the selection of the most suitable dimensions and form to secure economy of propulsion and good behaviour at sea involves the most thorough enquiry and experiment. The provision of ample structural strength in association with no excessive weight of material is another subject of the greatest importance requiring investigations such as have never been previously equalled in extent and thoroughness. In respect of the propelling-apparatus also, the great increase in power inevitable with the higher speed has necessitated unusually detailed con-

sideration. At the present time a committee, appointed by the Cunard Company, is engaged in an investigation of the possible application of steam-turbines to these vessels, instead of reciprocating-engines. Details of accommodation for passengers in vessels of the large size contemplated naturally raise many novel and interesting problems; the great experience of the Cunard Company and the ability of their staff ensure that these will be dealt with in a manner that will conduce to the comfort and convenience of passengers, while the decorative and artistic treatment will be of the highest character. All these and other features of the designs are interdependent, and as yet no definite decision has been reached. The published statements on the subject have been premature and unauthorized. Having been intimately connected with the work during the last year it may not be improper for me to say that everything possible has been done to secure success in all departments. Precedent has to be surpassed, but experience and experiment have been laid under contribution to the utmost extent.

Sixty-three years have passed since the Cunard Company commenced its Trans-Atlantic service with four wood paddle-wheel steamers of the "Britannia" class, the sea-speed being $8\frac{1}{2}$ knots. The vessels were 207 feet long, 34 feet broad, of 1,140 tons gross, developed 750 HP., and burnt about 40 tons of coal a day. The deep-load draught was about $17\frac{1}{2}$ feet, and the corresponding displacement about 2,200 tons. They carried ninety passengers, and had a cargo-capacity of 225 tons (weight). The contrast between these vessels and those to be built under the agreement marks the advance made since ocean steam-navigation was seriously commenced.

Development of Ocean Mail Steamships.

The Trans-Atlantic service has always, and naturally, taken the lead in increasing dimensions and speeds of steamships, but similar progress has been made on other great lines of ocean traffic. It is impossible to enter into details, but the following brief statement will illustrate what has happened.

The history of the Peninsular and Oriental Company is one of continuous growth, and under the guidance of Sir Thomas Sutherland the development of the fleet has been remarkable. There was a great advance between the little paddle-steamer "William Fawcett," which carried the mails to the Peninsula in 1829, and the "Ceylon" of 1858, for which particulars have already been

given. The "William Fawcett" was 75 feet long, and had engines developing about 120 HP.; she attained 8 knots under steam in favourable weather, but was largely dependent upon sail. Some years ago I met an engineer who had served on board this tiny mail-steamer, and had lived to see steamers of the same Company trading to Australia, China and India, having lengths of 450 feet to 500 feet, engines of 6,000 HP. to 8,000 HP., and speeds of 17 knots to 18 knots. The latest additions to the fleet are of the "Moldavia" class. The "Moldavia," built by Messrs. Caird, of Greenock, is 520 feet long between perpendiculars, 58¼ feet broad, and 37¼ feet deep. The gross tonnage is 9,500 tons, and the under-deck tonnage nearly 5,300 tons. Fully laden, the draught of water is a little under 27½ feet, the displacement approaching 15,500 tons. The twin-screw engines can develop 12,000 HP., and are intended to give a sea-speed of 18 knots, with a daily consumption of 180 tons of coal. The bunkers contain 2,000 tons of coal, and the dead-weight for cargo is 3,000 tons. About one-half the cargo-space is fitted for refrigerated produce. In this class the limitation of draught fixed by the Suez Canal is one of the governing conditions, and greatly influences possible earnings. The "Moldavia" can carry 348 first-class and 166 second-class saloon passengers, about one-sixth of the number contemplated in the "Great Eastern," also designed for the service to Australia. The time-table provides that, including calls at Marseilles, Port Said and Colombo, the voyage to Adelaide shall be made in 38 days. It is interesting to note that on this long-distance service the dimensions reached in 1903 are fairly close to those of the Trans-Atlantic liners of 1889, only the draught is less, and the displacement about 10 per cent. smaller, while the speed is 2 knots less and the engine-power only about two-thirds as great. Figures as to cost have not been published, but it can hardly be less than £300,000. The construction of these four vessels is justly said to mark an epoch in the history of the Company, an advance of nearly 20 per cent. having been made in the tonnage as compared with the largest preceding ships, and of 10 per cent. on the horse-power. They were too large for the Royal Albert Dock, and the fleet has been transferred to Tilbury.

It is interesting to remark in passing that the two new Allan liners—the first ocean-going passenger- and mail-steamers to be fitted with turbine-engines—are very close in dimensions and power to the "Moldavia." Mr. James Allan has furnished me with the following particulars. Length over all 540 feet, between perpendiculars 520 feet; breadth 60 feet, depth moulded 42 feet,

tonnage about 12,000 tons gross. The deep-load draught is over 28½ feet, the corresponding displacement about 17,000 tons, but on service this draught will rarely be reached. The boilers are capable of supplying steam for 11,000 HP., and the average speed in moderate weather is to be about 17 knots. There are to be three shafts, each carrying a screw-propeller, which, with the rapid revolution of the turbines, will be of much smaller diameter than twin-screws driven by reciprocating-engines would be. Mr. Parsons will not require in these turbines to go beyond the power of which he has experience, although there are many new conditions. Everyone interested in steam-navigation will wish him complete success, and Messrs. Allan are to be congratulated on their enterprise in making this new departure.

The Cape service also has just added to the great fleet of the Union-Castle line two splendid twin-screw steamers built by the Fairfield Company, and Messrs. Harland and Wolff. The dimensions are, approximately:—length at the water-line 570 feet, breadth extreme 64½ feet, depth moulded 42 feet; the gross tonnage is about 13,000 tons, the quadruple-expansion engines are to develop 12,500 HP., the steam pressure being 225 lbs., and the maximum speed should be about 18 knots. They will carry 350 first-class, 200 second-class, and 270 third-class passengers. This is an enormous advance upon the "Saxon" of forty years ago, for which particulars have been given.

Sir Donald Currie, who has communicated to me much information respecting the development of the Cape service, states that when he entered the trade in 1872 the vessels employed were of about 1,400 tons with a speed of 9 knots, the average passage being about 33 days. He placed ships of 2,500 to 3,000 tons on the line soon after, and reduced the passage to less than 23 days. Now there are vessels on service 570 feet in length and over 12,000 tons, having speeds of 17½ knots, while the average speed for the Union-Castle steamers in 1902 was 15 knots. Remarkable regularity is maintained in the times occupied on the voyage, the average homeward and outward voyage for the whole fleet differing by little more than an hour. The vessels are not working at their maximum speeds.

The latest vessels are about 30 feet shorter than the "Campania" and "Lucania," but otherwise of nearly the same dimensions. The engine-power is about one-half as great, and they are about 4 knots slower at full power. The voyage is more than twice as long as that to New York, and this is a most important factor in the design.

During the recent war the "Majestic," of the White Star line, was chartered, and it was found necessary (in order to cover the longer distance as compared with her ordinary run to New York) to work her at about the same speed as the regular Cape liners, in order to keep within the supply of coal available, even when extra amounts were carried. This was well understood, of course, by all connected with shipping, but the Press had teemed with complaints that the fastest steamers were not being employed at a time when reinforcements were badly needed. Probably the circumstance is now forgotten by those who agitated: at any rate it illustrates how the designs of ships are necessarily regulated to suit the circumstances of their employment.

The Orient Company, whose enterprise in adopting twin-screws has been mentioned, have vessels about 500 feet long, of 8,300 tons, 10,000 HP., and 18 knots maximum speed.

The Pacific Steam Navigation Company own the "Ortona," 500 feet long, of 8,000 tons, 10,000 HP. and 18 knots: the "Royal Mail" does not yet go beyond 420 feet, 6,000 tons, 6,600 HP. and 17 knots; but that is a great advance on the "Atrato," of 1860, described previously.

The West African steamship service dates from 1852, when the African Company was incorporated by Royal Charter; for more than twenty years it has been chiefly directed by Messrs. Elder Dempster & Co., and to Sir Alfred Jones I am indebted for the following facts. Fifty years ago four paddle-wheel steamers of about 700 tons, with good sail-power, sufficed for the service. In 1868 a typical screw-steamer was about 260 feet long, 30 feet broad, of 1,275 tons, carried 28 passengers, and averaged 9 knots, with a coal-consumption of 18 tons per day. The "Tarquah," recently built for the line, is 360 feet long, 44 feet broad, of 3,860 tons, carries 147 passengers, and can steam 13 knots on a daily coal-consumption of 45 tons.

Similar facts could be produced from other great steamship lines. The law of growth in size and speed has been universal.

In passing, acknowledgment must be made of the great services rendered to the Empire by the mercantile marine during the South African War. All the leading steamship companies co-operated in the transport of men, animals, food and munitions; the service was most efficiently performed; and His Majesty the King has recognized the value of the work done by conferring distinctions on representative officers. At the beginning of 1901, over 130 merchant-steamships, aggregating more than 700,000 tons, were thus employed, besides the vessels engaged in the

transport of Colonial contingents and on miscellaneous services. Up to the end of January 1901, nearly 250,000 officers and men had been conveyed safely to South Africa, together with their full equipment. These figures were subsequently greatly increased. No other country in the world could have accomplished such a result, and it should not be forgotten. The mercantile marine is an important factor in the defence of the Empire, although this is not its primary duty.

Intermediate Passenger and Cargo Steamers.

Reference has been made to the great development in recent years of vessels of the "intermediate" class, carrying large cargoes as well as a considerable number of passengers, at more moderate speeds than the mail-steamers, and at somewhat lower rates. Every great steamship-line has added such vessels to its fleet, and it is understood that they have achieved excellent commercial results. On the Atlantic service they include some of the largest vessels; the speeds already rise as high as 15 to 16½ knots, and it is probable that higher speeds will be adopted.

The "Cedric" has been described, and the "Ivernia" of the Cunard line is another excellent example. With her companionship, the "Saxonia," she possesses a reputation for exceptional steadiness at sea; she has a dead-weight capacity as large as the "Cedric," but is rather slower. Her dimensions are: length 580 feet, gross tonnage 13,800 tons, horse-power 9,500 HP., average speed about 15½ knots. The latest completed addition to the Cunard intermediate ships is the "Carpathia," also built by Messrs. Swan and Hunter, which is a little smaller and slower than the "Ivernia," with a length of 560 feet, 13,500 tons, 8,000 HP., and 15 knots. A novel feature in this vessel is that she carries no first-class passengers. At first she was fitted for only 200 second-class, and 1,700 to 1,800 third-class passengers; for the latter, excellent accommodation is provided in separate cabins. Third-class passengers now travel under conditions of comfort, not much if at all inferior, taking everything into account, to the accommodation given to first-class passengers 40 years ago. They can traverse 3,000 miles at a speed equal to that which was considered high for mail-steamers 30 years ago, at a cost of £5 10s., with food provided. The White Star "Britannic" averaged about 15 knots at the earlier period, carried a large spread of sail, was 455 feet long, 5,000 tons gross, developed 5,000 HP., and burnt 80 tons of coal per day,

The "Carpathia," with a displacement nearly 2½ times as great, maintains practically the same speed, with about 120 tons of coal per day; she carries not only a much larger number of passengers, but a dead-weight of cargo exceeding by 25 per cent. the total weight of the "Britannic" at her deep-load draught.

On their service to the East the Peninsular and Oriental Company employ intermediate steamers about 400 feet in length, of 4,100 tons to 4,600 tons, 3,500 HP. and 13 knots. On the Cape service of the Union-Castle line similar vessels have been employed for 12 years. The last constructed is the "Cluny Castle," 432 feet long, 5,000 tons gross, 3,500 HP. and about 12½ knots speed. She is intended to carry third-class passengers only, and if required can accommodate 700. In a recent speech Sir Donald Currie said that nearly two-thirds of the total tonnage of the fleet was now in "intermediate" steamers. This fact indicates the commercial value of the type.

The White Star Company have a service to Australia *viâ* the Cape—exactly that for which the "Great Eastern" was designed. I have been favoured by Mr. Bruce Ismay with the particulars for the "Suevic," built in 1901; they may be given in some detail as they indicate the progress made in half a century when contrasted with those previously given for the "Great Eastern." The "Suevic" is 550 feet long between perpendiculars (130 feet less than the "Great Eastern"), 63 feet broad (20 feet less), of 12,500 tons (6,400 less), 5,000 HP. (about 3,000 to 4,000 less), and 13 knots speed, with a coal-consumption of 80 tons a day, against 300 tons in the "Great Eastern" at the same speed. Taking the draught of 32 feet for both ships, the "Suevic" is nearly 6,000 tons less in displacement than the "Great Eastern," but has rather greater dead-weight capacity. She can carry nearly 12,000 tons of cargo in addition to the coal required for the complete voyage to Australia, and can accommodate 430 passengers. The latter item of course indicates a radical difference from the "Great Eastern," which could carry over 3,000 passengers; but experience seems to show that there is no necessity on the route to India or Australia to make such large provision. If it were considered desirable, which it clearly is not under existing conditions, to carry out Brunel's programme, and put on board the "Suevic," when she leaves Liverpool, coal enough to circumnavigate the world, she could still start with over 8,000 tons of cargo, and on the return voyage could carry 11,000 tons. These are very striking results, and appear the more so when earlier efforts at long-distance steaming are recalled.

These efforts displayed a boldness which is even now surprising. For instance, in 1825 the paddle-wheel steamer "Enterprise" made the passage from England to Calcutta *viâ* the Cape in 103 days, steaming- and sailing-time, the total time being 113 days. She was 122 feet long (on keel), 27 feet broad, of less than 500 tons burden (probably about 1,000 tons displacement), 120 HP. nominal (probably about 250 HP. indicated), and cost £43,000. In calm weather at her best she steamed 8 knots, but her steam-power was really an auxiliary to her good sail-spread. She ran 13,700 miles in 103 days—an average speed of more than 5½ knots; her greatest average speed in 24 hours was nearly 9½ knots; 39 days were under sail alone; she spent 10 days in re-coaling, and burnt 740 tons of coal.

The "Great Britain," designed by Brunel in 1843, was employed from 1853 to 1874 on the Australian service, and was for a long period the most successful vessel on the line. She was 320 feet in length (extreme), and of 3,400 tons burden, 3,000 tons displacement, and 10 knots to 11 knots speed. Her sail-power was ample, and was largely depended on. Good passages occupied about 45 days.

In 1865 Mr. Alfred Holt established a line of steamers to China, *viâ* the Cape, and worked it with great success until the Suez Canal was opened. This enterprise deserves notice as one among many services rendered to steam-navigation by Mr. Holt. It is interesting to note that Mr. Holt was a pupil of the late Mr. Edward Woods (Past President) when the latter was Engineer to the Liverpool and Manchester Railway. The ships were a little over 300 feet long, 38½ feet broad, 28½ feet deep, 2,270 tons, with engines of 300 HP. (nominal). So long as they went *viâ* the Cape they were fully rigged. Their steaming capability was excellent, and on their ordinary service they steamed to Mauritius without stopping, a distance of 8,500 miles. This was made possible by the use of higher pressures and compound engines, in the application of which to marine propulsion Mr. Holt took a leading position.

Cargo Steamers.

The characteristics and performances of cargo-steamers receive much less notice than do those of passenger-steamers, and the reasons are obvious. It is not too much to say, however, that the supreme position of our mercantile marine as over-sea carriers for the commerce of the world is chiefly due to the development of cargo-steamers. The story of that development cannot be attempted now, but it well deserves the telling, and illustrates the

skill and resource of shipbuilders and marine-engineers no less than does that of passenger-steamers. Increase in size and speed, enlarged carrying-power, greater economy in fuel, and diminished loss of life and property, are no less notable in cargo-steamers than in other classes. Numerous and widely differing types have been devised, as new trades have arisen or new conditions developed. To the onlooker this great variety is inexplicable; but every type has appeared in response to some new trade or fresh demand, or has been devised to cheapen the transport of food, fuel, oil, raw materials, merchandise and manufactured goods. The influence of legislation has been considerable, and, in the opinion of British shipowners, not always favourable to the shipping interest, which in recent times has had to encounter keen foreign competition. All such regulations are closely studied by shipbuilders and shipowners in order that earning capacity, in proportion to working expenses, may be made as great as possible. Tonnage laws influence types to no small extent, whether they be framed by the Board of Trade, by the Suez Canal, or other authorities. Load-line rules are also influential. Experience has led to the general acceptance of the principle of existing load-line legislation by British shipowners, whose contention—in my opinion a just contention—now is that foreign ships in British ports should not be permitted to load deeper than they would load if under our flag. There is obviously some need for change when a ship transferred from the British Register to some foreign flag can continue in the same trade and yet load more deeply in British ports.

The rules framed by Classification Societies, and especially by that great organization, Lloyd's Register of British and Foreign Shipping, greatly influence the construction of cargo-steamers, nearly all of which are classed with a view to advantage in insuring both ships and cargoes against marine risks. These rules deal with the scantlings of the hull on the basis of dimensions, with machinery and boilers, and with equipment; while under the Merchant Shipping Act the same Societies have powers to assign load-lines to new ships. Naturally a Classification Society favours ample strength and a large margin of safety, so that it is not surprising that shipbuilders should sometimes be of opinion that the scantlings and structural arrangements demanded are in excess of actual requirements. Lloyd's Register, however, has for many years past had the benefit of the advice of a representative Consultative Committee of leading shipbuilders and marine engineers, and in this way any real grievance is dealt with, or any desirable change in Rules initiated. The position which Lloyd's Register

has attained is indicated by the fact that, exclusive of war-ships, the vessels launched last year had an aggregate tonnage for the whole world of about 2,500,000, of which nearly 1,350,000 tons were classed at Lloyd's. Of the 1,427,000 tons launched in the United Kingdom 1,135,000 tons were classed. This is ample evidence that the Register has, on the whole, kept pace with the advance in ship-construction and done good service during its 70 years of existence. The other Registration Society, the British Corporation, was founded in 1890, and has done much useful work, but the scale of its operations is comparatively small. There are also foreign organizations, the Bureau Veritas being the principal. It is obviously of the highest importance that on their technical staffs these Registration Societies should have men of great professional ability and experience. This condition happily has been, and is, fulfilled, in both Lloyd's and the British Corporation.

Cargo-steamers include many and diverse types, adapted to the requirements of special trades and influenced by the conditions and limitations of the ports of call. Their structures and internal arrangements are governed to no small extent by the nature of the cargoes and the means which are essential to rapid shipment or discharge. All classes have to be capable of carrying heavy loads and bearing rough usage. Appearance counts for little; utility ranks first. Every detail affecting efficiency and economy in working is closely studied, and, as a result, sea-transport under modern conditions, as will be seen hereafter, costs marvellously little. While specialized types are numerous and necessary, the largest share of the work of the world in over-sea transport is still done by the much-despised "tramp" steamer, which "seeks" for cargo in all quarters, and manages somehow to accommodate most that offers, however varied the character may be. This marine "maid-of-all-work" when closely studied discloses features of a most interesting and perhaps unexpected character. Tramps make us the great ocean carriers; but the magnitude of their operations is not generally recognized, nor is their effect appreciated. In 1902 the United Kingdom owned 7,530 steamers of 100 tons gross tonnage and upwards. Of these only about 920 vessels have speeds exceeding 12 knots, and in that total are included a considerable number of steamers of the "intermediate" type carrying large cargoes as well as passengers, besides many channel-, coast-, and river-steamers. It is evident, therefore, that more than six-sevenths of our steamers are cargo-carriers. Another indication of the preponderance of the "tramp" is given when it is stated

that, in 1901, out of a total net (register) tonnage of British steamers of 100 tons and upwards approaching 7,500,000 tons, no less than 5,700,000 tons was included in vessels ranging between 1,000 and 4,000 tons (net). These are the vessels scattered far and wide over the seas, in many cases not returning home for long periods, which carry on most of the interchange of produce, raw materials and manufactures, and thus promote international relationships.

Steam Colliers.

The progenitor of this mighty fleet of cargo-steamers was an iron screw-collier built 60 years ago (1844) on the Tyne in a shipyard now belonging to Messrs. Swan, Hunter and Wigham Richardson. She was 150 feet long, 27½ feet broad, of 20 HP. nominal (perhaps 50 to 60 HP. indicated), and had a dead-weight capacity of 340 tons. She had a double bottom fitted for water-ballast, and probably could steam 7 to 8 knots. Her construction marked a new departure; but, strange to say, it has been generally overlooked, and the honour of being the first iron screw-collier fitted for water-ballast is usually attributed to the "John Bowes," built by Sir Charles Palmer at Jarrow in 1852. This was a larger vessel, carrying 650 tons, and her construction and success no doubt did most to further the building of iron colliers and the use of water-ballast. It was then a marvellous performance for a collier to make the trip from Newcastle to London and back in five days, and it was natural that she should be a prodigy when, in five days, "she accomplished an amount of work it would have taken two average-sized sailing-colliers a month to perform." I have often seen the old vessel at work on the Tyne when she was over 30 years old; what was her eventual fate I do not know.

It has interested me greatly to study the development of the steam-colliers employed in coasting and cross-channel work, since they were undoubtedly the pioneers who showed the way for over-sea cargo-steamers. By the kindness of Messrs. William Cory and Sons, who play so great a part in the coal-supply of London, and of other friends on the Tyne, it has been possible to trace the history of this development, and to see how great an advance has been made in economy and speed of coal-transport by sea from the coal-shipping ports to the Thames. Out of the mass of facts placed at my disposal, a few may be selected as of special interest.

The sailing-brigs formerly used between the Tyne and Wear and London were a motley fleet. Many of them were old before

they came into the trade; some of them reached a marvellous age for wood ships, centenarians being known. They carried 250 to 400 tons, and are said to have occupied on an average 3 to 4 weeks on the passage. The discharge on the Thames, by an old trade custom of the port, might be, and was sometimes, restricted to 50 tons a day. "Coal-whippers" did the work by manual power. When the cargo was discharged, came the process of "ballasting" by sand, gravel or rubble; this cost about 1*s.* 6*d.* a ton and occupied some time. The gravel-pits on the lower reaches of the Thames, and the ballast-heaps on the banks of the Tyne, remain as memorials of the scale of these operations. The time and cost of discharging this ballast were considerable items, the deposit fee on the Tyne being 10*d.* per ton.

Turning to present conditions, the finest steam-colliers trading between the Tyne and London carry more than 2,500 tons of coal, occupy 28 hours on the run when loaded, and are discharged at the rate of 250 to 300 tons per hour by special appliances with hydraulic lifting-power, carried by the floating pontoons, or "derricks," which Messrs. Cory and Son have established in suitable positions on the river. As the coal is discharged into barges, water-ballast can be admitted, and the vessel is ready to start on the return journey as soon as the holds are clear. In this rapid and economical fashion, and by means of an extensive and thoroughly-considered organisation based upon long experience and ably administered, Messrs. Cory deal with 5 to 6 millions of tons of sea-borne coal annually. A typical coasting collier of the present day is about 270 feet long, nearly 38 feet broad, 17 feet deep, 195 HP. (nominal), loads to about 18 feet, carries nearly 2,600 tons, and, fully loaded, can steam at 10 to 11 knots. In size and speed she considerably surpasses the earliest Trans-Atlantic steamers of the Cunard line.

Sea-going Colliers.

The coal exports from this country last year exceeded 60 millions of tons, and were valued at 27 millions sterling. This trade, therefore, is of great importance, employing large numbers of steamers, many of which bring valuable return-cargoes. Here, also, there has been great growth in size, carrying-power and speed. My friend, Sir William Lewis, M.Inst.C.E., has taken great pains to furnish me with information as to the vessels frequenting Cardiff, and we are under obligations to him for his kindness, as

this is a representative port. The sea-going colliers include a large number of vessels about 320 feet long, over 3,000 tons (gross), carrying about 5,000 tons dead-weight, and steaming 10 knots to 11 knots. Laden, the draught of water is about 23 feet to 24 feet. Many larger vessels, of about 5,500 tons, carry 7,000 tons to 7,500 tons, and a few specially-chartered vessels carry 10,000 tons to 11,500 tons. The largest cargo recorded was carried by a ship 470 feet long, 57 feet broad and nearly 32 feet deep—11,500 tons on a departure-draught of 27 feet. The sea-speed of most coal-carrying vessels seems to be from 10 knots to 11 knots. Members of the Institution are familiar, no doubt, with the special appliances at Cardiff and other great coal-ports for the rapid shipment of coal, and know that Welsh coal requires careful treatment. It appears that with vessels having suitable arrangements of hatchways and holds, 400 tons to 600 tons per hour can be shipped from railway trucks. Quick dispatch and short stay in port are essential. Much depends upon the construction of the ship, and single-deck colliers of large size are favoured. Special structural arrangements are, of course, necessary in such cases. There are also many so-called "self-trimming" devices intended to facilitate shipment of coal, but these need not be described.

For the Cape Breton and other coal-trades Messrs. Swan and Hunter have built recently some interesting vessels. The "August Belmont" of 1902, belonging to the Pensacola Trading Co., is an excellent example of a large modern single-deck collier. She is 372 feet long, 50 feet broad, 30·6 feet deep, of 4,639 tons gross, with about 7,000 tons dead-weight capacity on about 24 feet draught, and 11 knots speed on service. For rapid discharge of her cargo she is fitted with ten derrick-poles, and sixteen derricks, worked by powerful steam-winches. She has five holds and eight hatchways, the engines and boilers being right aft. In service she has proved very successful.

Water-Ballast.

Water-ballast, which came into use for colliers, has been extended to almost all classes of merchant-steamers in recent years, with marked advantage. Of course it is most important in vessels of great dead-weight capacity, which are subject to considerable variations of draught. Not infrequently such vessels have to make voyages with little or no cargo, and, both for stability and trim,

water-ballast is required. In many passenger-steamers water-ballast is used as coal is burnt out, the conditions of stability and steadiness being thus met satisfactorily. Liberal provision for water-ballast is usually made in cellular double bottoms, which add also to strength and safety. In some classes of cargo-steamers ballast compartments are formed in the hold; either by transverse bulkheads, or by wing-bulkheads running fore and aft. Certain types of ships, with great relative beam, require the ballast to be carried high up, in order to avoid excessive stiffness, and consequent quick and heavy rolling. All these questions now receive careful and scientific treatment. Experience is said to indicate that for cargo-steamers it is desirable to provide for a possible use of water-ballast amounting to one-third or one-half of the dead-weight capacity.

Recently there has been a Parliamentary enquiry into the question of a compulsory "light" load-line for merchant-ships. This, in other words, was a suggestion to legislate for the minimum draught to which British ships should be laden, existing legislation dealing with the maximum draught. It would have practically involved the prescription of the amount of water-ballast to be provided. After full enquiry and evidence as to losses through alleged under-ballasting, the Committee declined to recommend this new regulation. In common with the great majority of shipowners and shipbuilders, I personally rejoice at this decision. It is a matter that should properly be left to shipowners and naval architects to deal with. Freedom of design should never be hampered by legislation, it being always understood that clear responsibility is maintained and proper provision made for safety.

Evolution of the Cargo Steamer.

The provision of suitable hatchways for cargo-holds, and the arrangements of beams, pillars and structural details, so as to favour rapid loading and discharge, are the duty of the designer. According as this work is done efficiently or otherwise the earning powers of cargo-steamers are affected. Experience is here of supreme value. Numerous inventions have been introduced for increasing despatch, and "self-trimming" arrangements have been proposed repeatedly. With special cargoes, such as coal, ore or grain, the conditions of the problem are well defined and can be specially provided for. With general cargoes, varying greatly in character, it is more difficult to determine the best arrangements,

but a process of "natural selection" is in operation, and both shipowners and shipbuilders are keen to promote economy in working. In many trades, subdivided cargo-holds are advantageous; in others, clearer hold space is preferred; and in many sea-going ships of considerable size only a single deck is provided, with extremely large hatches, without weakness in the structures. In such cases the structural arrangements have to be suitably designed, departing widely from ordinary construction. These are only a few out of many instances that might be given of the almost endless variety of the work done by cargo-steamers, and the ingenuity and skill displayed by their builders.

The evolution of the cargo-steamer from the sailing-ship, and its gradual development, can be traced by those interested in such matters. At first the steamer was practically flush-decked like the sailing-ship, carried good sail-power, and had meagre protection for deck-openings over the engine and boilers. Light erections were then constructed above the main-deck in the form of poops, forecastles and bridge-houses. Internal space was necessarily trenched upon by requirements for engines, boilers, and coal; consequently greater depth was adopted and an additional deck was fitted. For many purposes it was preferred in some cases to make the superstructures lighter, or not to close them in completely; tonnage rules had much to do with these variations. Resultant types were designated "awning-deck," "spar-deck," "shelter-deck," "shade-deck," and "well-deck."

On the American lakes, "whale-back" steamers were introduced some years ago, and found great favour as carriers, offering special facilities for loading and discharge of cargo. One vessel of the type came to England in 1891 and attracted great attention in shipping circles. The extremely low freeboard, and practical surrender of the greater portion of the upper structure to free access of the sea, did not commend themselves to British owners as being well adapted for ocean navigation. But, out of the type, came the "turret-deck" steamers with which the name of Messrs. Doxford is associated, and the modification known as the "trunk" deck type. In both, the superstructures are narrower than the main structures of the ships, and the cargo-hatches are exceptionally large, being well protected by their height above water. It may be assumed that each of these various types gave some advantages, or it would not have been introduced. Many of them have ceased to be built; some have proved dangerous, unless carefully proportioned and suitably loaded. For the last 20 years scientific methods have been applied in the design of cargo-steamers,

with beneficial results. Many varieties still exist; but all are safe, sea-worthy, and wonderfully economical. The modern tramp is often a fine vessel, and the term is now used as a description of employment, rather than as a suggestion of inferiority in type or construction.

Economy of Transport Over-Sea.

Thirty years ago a cargo-steamer 250 feet long, 33 feet wide, 17½ feet deep, 1,500 tons gross, 3,000 tons dead-weight capacity was reckoned a large vessel, and 8 to 8½ knots was considered a fair speed. As sailing-ships have been driven out by steamers, even for the longest voyages, the sizes have grown, and there has been an increase in both dead-weight and speed. In 1890, steamers about 300 feet long and of 3,000 tons, carrying about 4,500 tons (dead-weight) at 8½ to 9 knots, were considered powerful vessels, although there were some exceptional vessels about 400 feet long, having a gross tonnage exceeding 5,000 tons and about 8,000 tons dead-weight capacity. Since then purely cargo-steamers about 500 feet long, of 8,000 to 9,000 tons (gross), with 11,000 to 12,000 tons dead-weight capacity, steaming 11 to 12 knots, have been built; while the intermediate type, already described, has reached 550 to 600 feet in length, 12,000 to 15,000 tons dead-weight, and 13 to 16 knots speed. But there still remain on service, doing good work, large numbers of vessels of 3,000 tons dead-weight capacity and 9 to 9½ knots speed.

Steel hulls and economical propelling-apparatus make these smaller vessels extremely economical in working. As an example, an actual ship 300 feet long, 35 feet broad, 24¼ feet deep, and nearly 22 feet load-draught may be taken, carrying 3,000 tons. At 9½ knots her daily coal-consumption is 15 tons; which means that each 1,000 tons of dead-weight can be carried one mile for a consumption of less than 50 lbs. of coal. Taking the price of coal as 15*s.* per ton this means that 1,000 ton-miles cost only 4*d.* for fuel.

An illustration of the increased economy obtained by increased size is afforded by comparing this performance with that of a ship 330 feet long, 40 feet broad, 26 feet deep, and 23 feet draught, carrying 4,200 tons. At 9½ knots her daily coal-consumption is about 19 tons, and for 1,000 ton-miles less than 45 lbs. of coal are expended, costing about 3·6*d.*

Another comparison may be made between two cargo-steamers steaming 11 knots. One is 365 feet long, nearly 47 feet broad, 30 feet deep and 24¼ feet load-draught, carrying 6,500 tons dead-

weight; the other is 470 feet long, 56 feet broad, and nearly 35 feet deep, loading to 27½ feet, with 11,500 tons dead-weight. The first burns 27 tons of coal per day, the second 45 tons; that is to say, the dead-weight is increased 77 per cent. while the coal-consumption is increased only 66⅔ per cent. On the same assumption as before the cost of fuel per thousand ton-miles is about 2·85 pence in the smaller ship and 2·65 pence in the larger.

If the larger of these two vessels were driven at 13 knots instead of 11 knots, the coal-consumption would rise to 80 tons per day, and roughly 500 tons more weight would be required for propelling-machinery, etc., leaving 11,000 tons dead-weight. The cost per 1,000 ton-miles would then be a little more than 4 pence,—nearly 60 per cent. increase on the cost for 11 knots. This is suggestive of what increase in speed entails, but it will be noted that this vessel, on account of her greater dimensions, carries cargo at 13 knots at nearly the same cost as the 300-foot steamer carries it at 9½ knots.

For 13 knots a still larger ship would be suitable, and the "Suevic," of the White Star Line, represents this type. Her dimensions have already been given. The cost per 1,000 ton-miles is about 3 pence, and an expenditure of about 3 shillings on coal drives 1 ton dead-weight from England to Australia.

The principle now finds general acceptance that, the longer the voyage, the larger must be the ship, if the freight is to be cheaper. If it is thought desirable, increase in dimensions can be utilized, partly in increasing speed, and partly in greater dead-weight, and the corresponding variations in freight depend upon the trade, voyage and speed. Recently a leading shipowner of large experience published the following figures: Coal shipped from the Tyne is carried to London (315 miles) for 3*s*. 3*d*. a ton; to Genoa (2,388 miles) for 5*s*.; to Bombay (6,358 miles) for 8*s*. 6*d*. The freights per 1,000 miles average respectively 9*s*. 3*d*., 2*s*. 1*d*., and 1*s*. 4*d*. On the longer voyages larger ships are used. When small vessels were used to transport grain from America the freight was 9*s*. 6*d*. per quarter; now it is 9*d*. per quarter from New York in the large cargo-carriers. Rice formerly cost 90*s*. per ton to bring from Rangoon to the United Kingdom; the freight has been reduced to 22*s*. or 23*s*. per ton.

Increase in dimensions, it will be remarked, is much greater in length, breadth and depth, than in draught of water. The 300-foot ship carrying 3,000 tons of dead-weight on 22 feet draught being taken as the starting-point of the series, the 550-foot ship at the other end is about 80 per cent. larger in

length, breadth and depth, but less than 50 per cent. greater in draught of water, and on many services she could not utilize the draught of 32 feet 9 inches, which corresponds to 15,000 tons dead-weight. Such a ship could be laden more deeply with perfect safety, and the gain in dead-weight capacity and economy in freights would be sensible. In fact it is in this direction of increased draught that the best results are possible, and, as remarked above, naval architects have appealed for years past to dock and harbour authorities for improvements; much has been done, but more must be done if commerce is to have its fullest development. In modern types of cargo-steamers there is a greater ratio of beam to load-draught than was the rule 25 years ago: this tends to more satisfactory conditions of stability, with the very varied cargoes that have to be carried. Formerly there was a general feeling that increase in beam was adverse to economical propulsion, but this prejudice has disappeared, and with increased lengths very remarkable economy is now obtained at the working speeds of these steamers, although they are of very "full" forms.

These illustrations of modern practice and the resultant economy make it easy to understand why steamers have gained upon sailing-ships, even for the longest voyages, in consequence of their greater certainty, regularity of service and higher average speed. Sailing-ships are still built, and there has been in recent years, a considerable revival in their construction in France under the bounty system. They find employment on long voyages or for minor trades.

The cargo-steamer is wonderfully light in structure for the load it carries. There are, of course, comparatively few fittings, the holds and 'tween decks being required for cargo, and the crews are small. The scantlings are comparatively heavy, as the large loads require corresponding strength, and the finish of the workmanship is not equal to that of passenger-steamers. Ample strength is, as a rule, obtained with ships in which the hull, outfit and machinery do not exceed 30 per cent. to 35 per cent. of the load-displacement, while hull and outfit do not exceed 25 per cent. to 30 per cent. in most cases.

First cost is also relatively small. A first-class cargo-steamer, having 6,000 tons to 7,000 tons dead-weight capacity, can be produced at present for about £40,000, as against nearly £50,000 two years ago. Even on the larger figures, the cost is remarkably low for a ship with such earning-power.

The North-East coast can claim to have led the way in the use of steam-colliers, and in this remarkable development of cargo-

steamers. Now "tramps" are built in many other ports, and the North-East coast, while maintaining its lead in this class of ship, undertakes the construction of all other classes.

Lifting-Appliances.

Increase in size and carrying-power of cargo-steamers has necessitated great developments in lifting-appliances, in order that the large cargoes may be rapidly shipped and discharged. It is well understood that "quick dispatch" in this matter is of the utmost importance, and that the length of time a ship has to remain in port between voyages greatly influences her earnings. Dr. John Inglis has dealt with this matter exhaustively, on the basis of carefully compiled data obtained from actual practice; and he has shown that a shortening of the time in port has a high commercial value. I have dealt with the subject of improvements in lifting-appliances elsewhere, and can only say, in passing, that the skill of the mechanical engineer, added to the carefully devised arrangements of the shipbuilder, have enabled the largest and heaviest cargoes to be rapidly dealt with. As an example, the "Cymric" may be again mentioned. Her dead-weight capacity is about 12,000 tons, and her measurement capacity nearly 800,000 cubic feet. A full cargo has been discharged, 1,600 tons of coal shipped, and a fresh cargo put on board between 7 A.M. on Monday and noon on the following Friday. The average rate of discharge was 300 tons weight per hour, and the corresponding rate for loading 250 tons per hour. In such a general cargo 30,000 to 40,000 packages were dealt with. More than 400 men were employed. Another recorded instance is that of the "Milwaukee," which discharged 11,000 tons dead-weight in 66 hours working time.

The device and installation, as well as the maintenance and working of these lifting-appliances on board ships, requires careful attention. Steam-power is most largely used, but hydraulic- and electric-power are frequently adopted. Such an increase of auxiliary machinery of course involves greater demands on the steam-generating apparatus and the engineering staff; while its influence on coal-consumption is sensible.

Oil-Tank Vessels.

Special types of cargo-steamers are produced as new trades are developed. The "tank" vessels, built to carry oil in bulk, afford a notable example of this fact. Proposals were made in this direc-

tion 30 years ago, and a vessel was built by Messrs. Palmer, at Jarrow, to carry oil in bulk, as well as a few passengers, between the United States and Antwerp; but she was never employed on the service. Thirteen years later there were only ten steamers carrying oil in bulk on over-sea voyages, and nearly all the oil was carried in barrels. In 1900, Lloyd's Register showed 174 steamers similarly engaged; in 1902 there were nearly 200. At first, vessels of moderate size, 230 to 240 feet long, and of 1,500 tons gross, were used; but, as in other classes, dimensions have been increased continuously, and some vessels now exceed 500 feet in length and 9,000 tons (gross); carrying over 11,000 tons deadweight at speeds of 11 to 12 knots. The "tanker" has thus overtaken the large cargo-carrier.

In structural strength, subdivision, pumping-appliances, provision for maintaining stability, and ballasting, these vessels have many special features. The original proposal of 1872, to associate passengers with oil-transport, did not then find favour, nor has it been repeated. But the system of so building tank-ships, that they can be successfully employed for carrying general cargoes on return voyages, has been carried out on a large scale, and we may hope to hear it described in the coming session. The cheap over-sea transport of petroleum in recent years has had much to do with its largely extended use for heating, lighting, lubrication and power, as well as its relatively low price. The largest steamer of this class yet built was completed by Messrs. Scott, of Greenock, in June last, for the Anglo-American Oil Company. She is of the "shelter-deck" type. Her length is 512 feet, breadth 63½ feet, depth 42 feet; displacement loaded about 21,000 tons, and deadweight capacity 12,500 tons, with provision for 11,000 tons of oil in sixteen separate tanks. When oil is not carried, a general cargo can be shipped. A limited number of passengers is provided for. Her twin-screw engines develop 5,500 HP., and the maximum speed is 14 knots.

Meat Carriers.

The over-sea transport of food-supplies, in ships fitted with refrigerating apparatus, is a still more recent and remarkable example of the adaptation of cargo-steamers to new requirements. This trade is not yet a quarter of a century old, but its growth has been enormous. It is stated that at the end of last year 147 steamers were engaged in the carriage of frozen meat and ten more were building. In the aggregate, these vessels can carry more than

9 million carcasses, and they are fitted with elaborate arrangements for insulation and ventilation of the storage-chambers, as well as with powerful refrigerating machinery. Here also there has been rapid advance in the dimensions of vessels and their carrying-power. A good illustration of this is found in the following particulars of vessels with which I have been favoured by Messrs. Hawthorn, Leslie and Co., who have had large experience of the class.

In 1888 a ship trading to Australasia was 350 feet long, 47½ feet broad, and 27 feet deep, and of 5,700 tons gross, and carried 41,000 carcasses; her sea-speed was about 12 knots. In 1899 the corresponding particulars were: length 457 feet, breadth 57·9 feet, tonnage 7,700, number of carcasses 92,000, speed about the same, engine-power double, and twin-screws instead of single screws. Still larger ships have since been built, one exceeding 470 feet in length, and of 8,000 tons, with capacity for 100,000 carcasses, and a sea-speed of 13 knots. The insulated chambers in the last vessel aggregate about 300,000 cubic feet, and her dead-weight capacity is 10,000 tons. She ranks, therefore, with the largest cargo-steamers in general trades. It is unnecessary to dwell on the influence which the work of these food-carriers has upon the welfare of our people and the trade of the Empire.

Cable-laying Steamers.

The use of submarine cables has made new demands on shipping, and has led to the construction of a special class, which last year numbered about forty vessels of various sizes. One of my earliest recollections is the presence in Devonport harbour of the screw line-of-battle ship "Agamemnon" and the United States screw-frigate "Niagara," which had on board the two parts of the first Trans-Atlantic cable. The "Great Eastern" was subsequently used for laying the second cable in 1865, and found employment in similar work for 10 years, laying the principal deep-sea cables. To the courtesy of the Telegraph Construction and Maintenance Company I am indebted for many interesting facts as to her service in this capacity. While she had many features admirably adapted for carrying and laying cables, her great size had some disadvantage, and she was costly in working. As a result the "Faraday" was specially built in 1874 for Messrs. Siemens by Charles Mitchell & Co. for laying an Atlantic cable. A comparison of her dimensions with those of the "Great

Eastern" indicates the great gain resulting from designing specially for the requirements of cable-laying rather than adapting a vessel originally built for another service. The "Faraday" is 360 feet long, 52 feet broad, 36 feet depth moulded, of 4,900 tons gross, fitted with twin-screw engines, giving a working-speed at sea of 8 knots to 9 knots, and a maximum speed of 10 knots. She is only about half as long, and little more than one-fourth the tonnage of the "Great Eastern," but she can carry 4,300 tons of cable, 1,400 tons of coal, and 150 tons of stores, at a load-draught of about 26 feet. Her success was complete, and involved the supersession of the "Great Eastern" in the work which had constituted her chief source of revenue since her completion. The "Faraday" was followed by the "Hooper," and since then the class has been greatly developed.

At present the largest cable-laying ship on service is the "Colonia," built last year for the Telegraph Construction and Maintenance Company by Wigham Richardson & Co. This vessel is 487 feet long, 56 feet broad, 39 feet depth moulded, of 8,000 tons gross, fitted with twin-screws, and capable of easily maintaining 12 knots to 13 knots at sea when deeply laden. The owners have furnished me with the following particulars.

On her first voyage in the Pacific in 1902 she carried 7,684 tons of cable (3,540 miles), besides her coal and stores, on a draught of 26 feet. She steamed 34,600 miles on the voyage, and consumed 8,900 tons of coal in 5 months and 10 days. The cable was "paid out" at the rate of 210 miles per day, and the maximum depth of water in which the cable was laid was 3,400 fathoms. In 1870 the "Great Eastern" laid the cable to Bombay. She carried 5,512 tons (2,375 miles) and her coal and stores on a draught of 35 feet. On the voyage she steamed 23,500 miles, and burnt 25,000 tons of coal in 7½ months. The speed of paying out cable was 160 miles per day, and the maximum depth of water 2,060 fathoms. The "Colonia" is nearly 200 feet shorter than the "Great Eastern," 27 feet narrower on the hull, 64 feet less in extreme breadth (paddle-boxes in "Great Eastern"), 11,000 tons less tonnage, yet she carries over 2,000 tons greater weight of cable, and draws 9 feet less water when fully laden and stored, with bunkers full; she laid the cable at an average speed 2 knots greater than that of the "Great Eastern," in much deeper water, and steaming 11,000 miles more she consumed 16,000 tons less coal. The contrast is startling, and many causes contribute to it. Reference need only be made to the fact that the "Great Eastern" was unnecessarily large for

the service of laying cables, having been designed with great internal capacity for accommodation of passengers and cargo; while her propelling-apparatus was relatively very heavy, and wasteful in coal-consumption.

"Turret" Cargo-Steamers.

This type grew out of the American "whale-back," as already described. It was introduced and has been principally built by Messrs. Doxford, of Sunderland, and, like all other types, has been greatly increased in dimensions. The first vessel was 280 feet long, 38 feet broad, and 22¾ feet depth moulded, of nearly 2,000 tons, 800 HP., 8 knots speed, carrying 3,200 tons dead-weight on 18 feet draught. More than 100 vessels of the type have been built since. The latest, for general trade, is 390 feet long, 55 feet broad, 30 feet depth moulded, of 5,500 tons, carrying nearly 9,000 tons on 24 feet draught, at a speed of 10 knots, with 1,900 HP.

The largest turret-steamer afloat is the "Grangesberg," built to carry ore from a Swedish port to Rotterdam. She is in many respects novel and interesting. Her length is 440 feet, breadth 62 feet, depth moulded 29 feet, 6,570 tons, with a dead-weight capacity exceeding 10,000 tons on 22¾ feet draught. Her engines develop 2,200 HP., and the speed is 10½ knots. She is "single-decked." The appliances for rapid discharge of ore are very special. There are twelve large hatchways, the vessel being built with six separate compartments for ore. Seven pairs of masts, each 56 feet high, are fitted in pairs abreast, and carry 24 derricks, worked by 12 double-ended winches. Abreast each hatchway, and on each side, are 24 portable platforms upon which the ore is emptied when lifted from the hold, and thence it can be sent into barges through "shoots." The whole cargo of ore, it is anticipated, can be discharged in about 35 hours. I saw this vessel outside the Tyne on her trials recently, and failed to recognize her type or intended service, her appearance being altogether unusual. In my time I have seen some strange floating structures, designed for war-service, but never any surpassing the "Grangesberg." Her early voyages are said to have been most successful, and if, as her owners hope, she makes twenty trips each year, she will perform the remarkable feat of shipping, carrying and discharging 200,000 tons of ore per annum.

Cross-Channel and Coasting Steamers.

Cross-channel and coasting steamers are distinguished in many features from ocean-going vessels; but their primary distinction lies in their comparatively short runs, and the consequent small importance of economy in coal-consumption. Passenger-steamers on cross-channel service have for more than half a century been remarkable for high speed in relation to their size, and for relative lightness of construction in hull and machinery. On every line of traffic there has been progress in speed and accommodation; many new lines of high-speed steamers have been established, and recently the use of turbine-engines has given a fresh start to design, with the prospect of sensible advance. In many instances progress has been delayed, or made difficult, by unsatisfactory conditions of space and depth of water in the harbours; this has been especially true of the English Channel, but fortunately much has been done to remedy the evil; and naval architects now have greater opportunities of improvement in designs, because dimensions are less restricted.

Naturally one thinks of the Dover-Calais route first. Here steamers were introduced in 1821, and up to 1856 the vessels in use did not exceed 170 feet in length, with maximum speeds of 14 knots to 15 knots. In 1861–2 a great step was taken by the construction of the "Samphire" class, which were remarkable vessels in many ways. Their hulls were steel-built, when steel was difficult to obtain of suitable quality, and the cost was very high. The paddle-wheel engines were also exceptionally light and powerful, developing about 1,000 HP. on trial, with a corresponding speed of 17 knots. The length was about 190 feet. extreme draught less than 7 feet, displacement and gross tonnage each about 340 tons. For 20 years these vessels continued at work; and those concerned with their construction had every reason for satisfaction. Since 1882 many larger and swifter vessels have been built, and the improvement of the harbour at Calais has permitted deeper draught. The latest addition is the turbine-engined triple-screw "Queen," 310 feet long, 40 feet broad, 25 feet deep, with engines and boilers capable of developing about 8,000 HP., and driving the vessel about 21 knots to 21½ knots. She is the first screw-steamer on this route, and the high rate of revolution of the turbines permits considerable economy of weight as compared with reciprocating-engines, as well as much smaller screws. The reports on her working have

been most satisfactory in all respects; and already a number of similar vessels have been ordered for other lines. The "Queen," as is well known, was preceded by two turbine-steamers on the Clyde, and a somewhat smaller vessel was built simultaneously for the service between Newhaven and Dieppe. She has realized 21½ knots on service. Mr. Parsons is to be congratulated on the fact that at length, after years of experiment and investigation, the merits of the system, which we owe to his genius, have been recognized in the mercantile marine. Messrs. Denny also deserve the thanks of all interested in the progress of ship-construction for their courage in undertaking these pioneer vessels, and the skill shown in their design. At present two turbine-vessels are building for the Midland Railway service to Belfast; a third is in hand for the Stranraer and Larne route; and a fourth for the much longer run (nearly 280 miles) between Melbourne and Tasmania.

Schemes have been framed for carrying trains across the Straits of Dover in high-speed ferry-steamers, and on the shipbuilding side there is no great difficulty. Some eminent firms have prepared designs for this service; and personally I worked out a design, in conjunction with Sir John Fowler's proposals for the harbour-works, about twenty years ago, when the Government refused to sanction the construction of a tunnel. The decision not to create this through service rests upon other considerations than the problems of ship-designing involved. Indeed, these are greatly simplified by the harbour improvements and the depth of water available, as compared with the conditions of twenty years ago.

The Holyhead-Kingstown route has long been distinguished for high speed. In 1860 four iron paddle-wheel vessels named after the provinces of Ireland stood far above all other cross-channel steamers in size and speed, and the present vessels maintain relative superiority. Here there are no such extreme limitations of draught as prevailed so long at Calais, and the results were marked. The "Leinster" of 1860 was 328 feet long, 35 feet broad and of nearly 13 feet draught of water: her displacement was 1,900 tons, maximum speed 17¾ knots, with 4,200 horse-power. In 1896, under a new contract, four twin-screw steel steamers were built and were given the same names. They are 360 feet long, 41½ feet broad, about 13 feet draught and 2,200 tons displacement, attaining a maximum speed of 24 knots on trial with more than 9,000 HP. In their predecessors the steam-pressure in boilers was 25 lbs., and the oscillating paddle-engines made 26 revolutions per minute, the piston-speed being about 340 feet per minute. The new vessels have a steam-pressure of 175 lbs., and their vertical triple-

expansion twin-screw engines make 175 revolutions per minute, the piston-speed being 960 feet per minute. Forced draught is employed in the stokeholds. With the consequent economies in weight of hull, propelling-apparatus and rate of coal-consumption, it was found possible by Messrs. Laird (who built three of the earlier and all the later vessels) to add over 6 knots to the speed, in association with improved and enlarged accommodation, by an increase of about 30 feet in length, and only 300 tons in displacement. The engines, boilers, etc., in the later ships are not 10 per cent. heavier than those of the earlier ships, although they develop more than twice the power, and the coal-consumption on the passage is probably no greater, owing to superior economy in propelling-apparatus and shorter time on passage.

A similar story of progress in size and speed might be told for many other cross-channel routes. For example, the fastest South-Western steamer from Southampton 14 years ago was of 1,100 tons displacement, 2,250 HP. and 16½ knots speed; now vessels are running of 1,500 tons, 5,300 HP., and nearly 20 knots speed. On the line from Fleetwood to Belfast vessels of 2,200 tons, 5,800 HP., and 20 knots speed are employed; and the Isle of Man service possesses a paddle-steamer 360 feet long, 42 feet broad, and 25½ feet deep, drawing 12½ feet, which developes over 12,000 HP. and exceeds 21 knots speed.

Some interest attaches to a special steamer of this class, the twin-screw "Princess Victoria," recently built by Messrs. Swan and Hunter and engined by Messrs. Hawthorn, Leslie & Co. for the Canadian Pacific Railway, because of the fact that she has successfully performed the long voyage from the Tyne to her station at Vancouver although so lightly built. Some of the superstructures and fittings were not put in place until her arrival, but in other respects she was complete. Her length is 300 feet, breadth 40½ feet, and depth 17½ feet. She has attained the speed of 20 knots on a run of about 90 miles, developing about 5,000 HP. She proceeded to Vancouver by the Straits of Magellan, at an average speed of 12½ knots, and sustained no structural damage on this long and tempestuous voyage.

Closely related to cross-channel steamers, but designed to cover much longer distances, are vessels like the "Isis" and "Osiris," built five years ago by the Messrs. Caird for the Peninsular and Oriental Company's rapid mail-service from Brindisi to Port Said —about 940 miles. These vessels are 300 feet long, 37 feet broad, and 18½ feet deep. They carry no cargo, and only 70 first-class passengers besides the mails. Loaded they draw about 15 feet,

and have a displacement of 2,500 tons. On trial they exceeded 20⅓ knots, developing about 6,500 HP. On service they can attain 19 to 19½ knots if required; and make the passage in 50 hours. Their coal-supply is necessarily large as compared with cross-channel steamers, and they have proved excellent sea-boats on voyages through proverbially stormy seas.

It is interesting to note that in dimensions, displacement, maximum speed and power these vessels approximate closely to the third-class cruisers of the "Pelorus" class, which I designed in 1894. These cruisers have to carry relatively large weights of armament and protective decks, to which there is nothing corresponding in the "Isis." They are not designed to maintain maximum speed for long runs, but have proved themselves capable of developing over 4,000 HP. and about 16 knots speed for the time their coal would last. They have water-tube boilers, with tubes of small diameter, and engines running at 220 revolutions for maximum power; as against cylindrical boilers and engines running at about 150 revolutions in the passenger-steamers. The weight of propelling-apparatus is consequently only about one-half that in the "Isis" and "Osiris," and this saving in weight goes towards armament and protection. The comparison is of interest, as indicating how differently the available displacement must be distributed in ships designed to fulfil different services.

Coasting steamers are mostly of much lower speed than cross-channel steamers, and they carry cargo as well as passengers; they also have to cover longer distances. In this class, however, size and speed have grown greatly, and 16 knots an hour is reached in some cases; but 14 knots is still reckoned a good speed.

Passenger-steamers working in estuaries or along the coast in many instances run at very high speeds. On the Clyde there are vessels of 20 knots, and on the Bristol Channel equal speeds are attained by comparatively small paddle-steamers. In lightness of hull and machinery, and in small draught these vessels are remarkable; they are licensed to carry large numbers of passengers.

Shallow-Draught Screw-Steamers.

Another interesting class of steamer which has been greatly developed in recent years is that having extremely shallow draught, but fitted with screw-propellers. Formerly, in such vessels, paddle-wheels, fitted either at the side or at the stern, were almost universally employed. The engines in these paddle-steamers

were slow-moving and heavy as compared with screw-engines; but the extremely shallow draught was regarded by nearly all designers as an insuperable obstacle to efficient screw-propellers. In 1856, a plan was patented for forming a tunnel near the middle of the length, in which the screw might work, the upper blades being above the water-level when the boat was at rest.

Nearly twenty years later Sir John Thornycroft initiated a type that has since been much developed, by building a twin-screw launch 63 feet long and 2½ feet draught; the screws were 3 feet in diameter and worked in tunnels near the stern. This little vessel attained the remarkable speed of 16½ (statute) miles per hour, and proved capable of towing a *dahabieh* on the Nile at a speed exceeding 9 knots. Other vessels followed, in which, instead of ordinary propellers, special "turbine" screws with small diameter and "coarse" pitch-ratio were employed; guide-blades were fitted abaft the screws and considerable efficiency of propulsion was attained. When the expedition for the relief of Gordon was organized Messrs. Thornycroft built five steamers, drawing only 21 inches of water; they were 140 feet long and 21 feet broad, but they attained a speed of 17½ miles.

In 1897, it was decided by the Admiralty to build a number of shallow-draught gunboats for service on rivers and estuaries. I naturally turned for assistance to the firm who had achieved these results, and they furnished me with full information. On this basis I prepared outline designs for two classes of gunboats. The features of speed, draught, equipment, armament, protection and accommodation were fixed; but I advised the Admiralty to leave to the firms invited to tender, the power of varying dimensions; subject to their acceptance of guarantees for speed and draught. This was done, and the orders were placed with Messrs. Thornycroft and Messrs. Yarrow, both of whom executed their contracts in an entirely satisfactory manner. The vessels were built in separate sections, each "floatable"; and could thus be readily carried on board ships, as well as rapidly put together on their stations. The smaller vessels were 100 feet long, 20 feet broad, 23 inches draught (with 40 tons load) and 10½ miles speed; the larger were 145 feet long, 24½ feet broad, 2 feet draught and about 15 miles speed. During the last six years these little vessels have done good service on the Niger, the Yang-tse and the Canton river. Others of the class have since been built, the largest being 160 feet long, 24½ feet broad, 27 inches draught and 15 miles speed, when burning wood only.

It may be interesting to add that, when the final advance on

Khartum was in preparation, Lord Kitchener consulted me as to the construction of light-draught gunboats of higher speed than any then on the Nile. After a conference, in which the features of our naval gunboats were described, it was decided to adopt the larger type (about 140 feet long), and the chrome-steel system of protection, which I had previously adopted for our vessels. Certain modifications in the nature and disposition of the armament were desired by Lord Kitchener, and were embodied in the design. The construction was entrusted to the same two firms, who performed their task expeditiously, and in a manner worthy of their reputation. These gunboats did good service in the advance up the Nile, in the fighting at Omdurman, the voyage to Fashoda, and subsequent operations. They were heavily-laden at times, and used for towing—both conditions being, of course, adverse to speed and efficiency of propellers, and not contemplated in the design.

There is doubtless a large possible employment for shallow-draught steamers on rivers and canals, and for exploration in distant regions. The use of turbines instead of reciprocating-engines enlarges the scope of designers. My own conclusion is that, on the whole, ordinary propellers are to be preferred to turbine-propellers and guide-blades, taking into account movement astern as well as ahead, and steering-power. No doubt the efficiency of the propellers can be increased by means of special devices, and it may be anticipated that those who have done so much to develope the type will carry its improvement further. The internal-combustion engine offers one opening for advance; only, in many regions, the supply of oil cannot be ensured; and wood fuel must, of necessity, be used.

Steam-Ferries for Railway Trains.

Allusion has already been made to railway steam-ferries in connection with the Calais-Dover passage, but while in that case the plan remains in the stage of a project, there are many examples of the successful employment of such vessels to convey railway trains across wide rivers or arms of the sea. In Denmark, for example, for 30 years the system has been adopted, chiefly for the conveyance of goods, but to some extent for through passenger-carriages. The fact that there are no tidal variations of importance, makes the shipment or debarkation of the trains a simple matter. The largest ferry in use in 1897 was nearly 300 feet long, and 34 feet broad, drew 9 feet of water, and steamed 13

knots on service with 1,400 HP. She was propelled by paddle-wheels, was double-ended, and had two lines of rails on her upper deck, carried by strong longitudinal girders. Passenger-saloons, well heated, lighted and ventilated, were fitted below the upper deck.

This year a bolder application of the system has been made by the establishment of steam-ferries between Gjedser, in the Island of Zeeland, and Warnemunde, on the coast of Mecklenburg. This involves a run of about 27 nautical miles on the open water of the Baltic. My friend and former pupil, Captain Tuxen, Director of Naval Construction of the Danish Navy, has been concerned with the designs for the vessels and has given me particulars. There are four ferries, two paddle-wheel and two screw. The former is designed to take an express train and passengers, a load of 180 tons. Her length is 285 feet, breadth of hull 36 feet, over paddle-boxes 61½ feet, draught 12 feet, and speed about 14 knots on trial; on service, probably 13 knots to 13½ knots. The twin-screw steamers have two lines of rails and are intended for goods chiefly; the load provided for is over 300 tons. Length and speed are the same as the paddle-boats'; the extreme breadth is 58 feet, and draught 13½ feet. This experiment will be watched with interest. Messrs. Schicau, of Elbing, are the German shipbuilders engaged on this international undertaking.

Steam railway ferries have also been constructed in this country, and Mr. H. Swan, M. Inst. C.E. (of Armstrong, Whitworth & Co.), has had special experience in this class. Two vessels built by him for Russia are specially interesting. One for the Volga, near Saratoff, is a twin-screw steamer 252 feet long and 55½ feet broad, with a draught of about 5 feet only. She has four lines of rails on her deck, and two hydraulic lifts at the bow for dealing with the railway-wagons when loading or discharging. The variation in height of water in the river is as much as 45 feet, but it is stated that twenty-four cars can be loaded or discharged in half an hour. This ferry and a companion ice-breaker maintain an uninterrupted service through the winter. The alternative scheme for a bridge was estimated to cost about a million sterling.

A still larger vessel is the ferry for the Siberian Railway across Lake Baikal, built by the same firm. She is 290 feet long, 57 feet beam, 28½ feet deep, of 4,200 tons displacement, has two screws aft and one at the bow, and developes 4,000 HP. Three lines of rails are laid on the deck, and, as the variation in height of water is small, the carriages and trucks are loaded or discharged over a movable gangway. When on board, the carriages are sheltered by a superstructure, in which ex-

tensive accommodation for passengers is provided. The passage across the lake is 40 miles, and very stormy weather prevails. The vessel acts as her own ice-breaker. It is reported that continuous railway communication will be eventually secured round the shores of the lake.

ICE-BREAKERS.

Ice-breakers are a class of vessels the use of which has considerably extended in recent years, both in Europe and in North America. The form of the vessels forward is arranged so that they can be driven on to the ice, and over-riding it can, by their weight, break through. It was thought that greater breaking-power would be obtained by fitting a screw-propeller at the bow, to work under the ice and drive the water astern. After trial this system has been abandoned. The "Ermak" is by far the most powerful vessel yet built for this service, having been suggested by Admiral Makaroff, of the Russian Navy, and built in the yard directed by Mr. Swan. She is 305 feet long over all, 71 feet beam, 42½ feet deep and 18½ feet draught. Her hull is built of mild steel and is exceedingly strong. The frames are only 12 inches apart, and the plating on the "ice-belt" is 1¼ inch thick. She is subdivided into forty-eight compartments. Her displacement is 8,000 tons, and the four engines develop 10,000 HP. There are three propellers astern; a fourth was originally fitted under the bow, but has been removed after trial. It is reported that in the Baltic she has been driven at a speed of 10 knots through clear ice 24 inches thick, and that ice 18 inches thick has little effect upon her. In polar regions the ship is said to have successfully encountered ice 7 feet in thickness, and Admiral Makaroff seemed hopeful at one time of making good progress towards the North Pole in his ship. Like many other attempts in that direction this did not succeed. But in boldness of conception, and in excellence of design and structure, the "Ermak" will always hold a prominent position. What the expenditure upon her has been is not stated, but in the Baltic she has proved of great value in maintaining navigation during the winter.

SAILING AND STEAM YACHTS.

It would be improper to leave unnoticed the important and popular branch of naval architecture which deals with the design and construction of yachts; but only a passing reference can be made thereto. Fortunately for the nation there still prevails a

love of the sea and of yachting as a recreation and sport. The beneficial influence of this characteristic it is difficult to over-estimate. His Majesty the King—himself a keen yachtsman—has done much to encourage yachting for many years past, and has owned very successful racing yachts. His Majesty the German Emperor, with that remarkable perception which distinguishes his conduct of affairs, has fully appreciated the close connection existing between yachting and the growth of the maritime spirit in a country. His efforts to develop yachting in Germany have been concurrent with, and not inferior to, his efforts to develop the mercantile and war fleets. In all these directions much has been done in recent years in Germany. The United States possess a splendid fleet of yachts, and other countries show great interest in yachting; but it may still be claimed that the United Kingdom leads the way in this class of shipping, and has an unquestioned supremacy.

Lloyd's Yacht Registers contain particulars of the number and tonnage of the yachts owned by various countries. The issue for 1903 gives the following figures, excluding the United States and Canada. Out of a total of 1,412 steam yachts with 196,000 tons aggregate tonnage the United Kingdom owns 885 vessels, of 108,000 tons, and British Colonies 65 vessels, of 3,200 tons; together 950 vessels, of over 111,000 tons. France owns 162 vessels, of 15,600 tons; Germany and Austria 43 vessels, of 7,900 tons. The grand total for sailing-yachts is 5,231 vessels aggregating 93,000 tons, out of which the United Kingdom owns 3,064 vessels, of nearly 60,000 tons, and the Colonies 325 vessels, of 4000 tons; together 3,389 vessels, of more than 63,000 tons. For the United States and Canada the Register shows 850 steam- and power-yachts of 30 feet length and upwards: and 1,939 sailing-yachts of not less than 25 feet in length. The tonnage of these yachts cannot be stated, as many of them are not officially measured.

Steam-yachts are of comparatively recent date, but there has been in them a great growth in size and speed during recent years, and in their construction full advantage has been taken of the sources of improvement above described. The most improved types of machinery and boilers have been adopted; steel has been used for the hulls, and scientific methods have been followed in the designs. The type in which good sail-power is associated with moderate steam-power, of which Lord Brassey's "Sunbeam" is such a fine example, still persists; but, as power and speed have been increased, in many instances sail-area has been reduced to narrow limits, and sail is used only under very favourable condi-

tions, or for steadying purposes. When twin-screws are adopted, of course, sail is of comparatively little value, except to economize coal in making long passages. A moderate number of men suffices for working these light sails, while the engine-room complements are considerable in number. In turbine-engined yachts, of which a few are already built and more will speedily follow, triple-screws are used; so that sail becomes even less useful, and may practically disappear. A splendid example of this class is the "Lorena," completed this year, 269 feet in registered length, more than 250 feet long on the water-line, 33½ feet broad, about 13 feet draught and 1,600 to 1,700 tons displacement. She attained 18 knots on trial, and her engines are said to develop more than 4,000 HP. The "Lorena" is undoubtedly a fine sea-going steamship, capable of performing the longest voyages at considerable speed, as she carries 480 tons of coal; but it is hardly likely that there will be many of the type, as the cost is so great. Mr. Parsons states that the use of turbines enabled him to reduce the size of engine-room considerably, besides saving 70 tons in the weight of machinery as compared with reciprocating-engines. There can be no doubt that this economy of weight, and reduction in the height of engines and engine-room, render turbines particularly suitable for yachts. Moreover, there are the gains of possible increase in accommodation, freedom from vibration, less cost of maintenance, supervision and lubrication—all important features in a yacht.

Other and larger steam-yachts have been constructed previously: such as the "Giralda" of 1894, owned by the late Colonel McCalmont, which was 289 feet long (register) and attained about 20 knots speed; the "Valiant" of 1893, 308 feet long and heavily rigged in addition to her steam-power; and the "Atmah" of 1898, 314 feet in length, 34 feet broad and 19 feet deep. The "Varuna," built by Messrs. Inglis in 1896, was 273 feet long, and proved exceptionally successful. The list of these large yachts might be greatly extended, but no useful purpose would be served. Enough has been said to indicate that British shipbuilders hold a great lead in this branch of construction, and are likely to retain it.

Sailing-yachts still remain prime favourites, although steam-yachts are multiplied. For cruising and racing the true yachtsman adheres to sails; and in the rigging, equipment and sail-making, lie three most important elements of success, enabling, as they do, skill in management to have free scope. The modern yacht-designer, under the stress of keen competition, has to study every detail minutely, and to work out the drawings and calculations on scientific principles. Beauty of form, excellence in

accommodation, taste in decoration, are all the objects of his care; but considerations of stability, power to carry sail, under-water form, and maintenance of speed in different kinds of weather, demand his utmost skill. Tonnage-measurements, rating-rules and time-allowances have large influence. Every successful designer of racing-yachts makes it his business to "cheat the rule" as far as possible and to gain the greatest time-allowance. As rating-rules are varied, corresponding variations of type are produced. Some rules have had bad effects on sea-worthiness or safety; but the general effect has, no doubt, been of a more satisfactory character. Still, it always remains true that a yacht built primarily for competitive sailing is "a racing machine," and that other qualities must be more or less sacrificed to speed.

Lightness of hull and fittings is carried to an extreme. Strong materials are employed, and the most careful workmanship is secured almost regardless of cost. Sails are made of silk, spars are hollowed, rigging is made of special quality, and many other devices are used to reduce weight aloft. All these savings in weight are utilized in ballast, and in other directions, to gain sail-power. The bottoms are burnished to diminish friction, and the weights of equipment are minimized. The crews are specially selected and trained, and the captains are men of exceptional ability. A racer is a triumph of skill and organization throughout; no expense is spared, and the "tuning-up" prior to the struggle is a process requiring much time and expenditure, in order that trim and sail-spread may be at their best.

Under such conditions, differences which are apparently small may obviously have marked effects The contests for the America Cup have furnished many illustrations of this fact. Moreover, British yachts, having to cross the Atlantic, cannot be built so lightly as the American yachts, even when special strengthenings are fitted for the voyage and jury-rig is adopted. In common with all British naval architects, I recognize fully the skill and resource which the American designers have shown, and admit that these qualities have had much to do with the result. There seems reason, too, for believing that, in organization and smartness, the American crews have been somewhat superior, while the captain in the last contest showed exceptional ability throughout. Admitting all this, there can be no question but that yachts which have to cross the Atlantic are substantially handicapped; and it is notable that American yachts, which have been sent to Europe to race, have not maintained a reputation equal to that they had acquired by performances in their home waters.

One feature of modern yacht-designing deserves mention in conclusion. Formerly the utmost secrecy was observed as to the forms and characteristics of yachts. Now, thanks in no small measure to the late Dixon Kemp, detailed information is available as to the form, stability and sail-equipment of all classes. Of course, in a great contest like that for the America Cup, precautions are taken for a time to keep from competitors information as to the features of the challenger and defender. When the race is over, full particulars are generally published.

Progress in War-Ship Building: 1860–1903.

In the foregoing review of mercantile shipbuilding, I have occupied the position of an intelligent and interested observer of work done by others. From the commencement of my professional career that branch of work has been constantly watched by me, not merely because of the constant progress made, but for the purpose of gaining information and suggestions that might assist my own special work. During that time it has been my good fortune to enjoy the friendship of most of the leading shipbuilders and shipowners of the country, and of many foreign shipbuilders. Since my enforced retirement from official life, it has happened that my study of the conditions of mercantile shipbuilding has been more thorough and detailed than ever before, on account of my connection with the design for the new Cunard steamships to be built under the Agreement with the Government; and in that work it has been in many ways advantageous to have previously been chiefly engaged in war-ship construction, and so to have an open mind.

Now that it is necessary, in this Address, to describe recent war-ships, it is unavoidable that my long connection with their design and construction should influence my views of both the past and the present. My endeavour, however, is to deal chiefly with facts rather than opinions, and to illustrate progress without assigning credit or discredit to those who have been responsible for war-ship designs. It is most difficult to summarize or to select from the great mass of facts in my possession, and to indicate the more important steps in the continuous and remarkable developments which have taken place since the "Warrior" was begun in 1859. Probably the simplest and most useful way of attaining that object will be to give particulars of typical ships constructed at different periods, and to make brief comments thereon.

It has been indicated that in 1859 France had a considerable lead in ironclads, having acted decisively and on a carefully-considered programme, while in this country controversies raged, and the responsible authorities hesitated. After the effort of ordering four iron-built ironclads in that year there came a pause, and further action was not taken until 1861. Then six more iron-hulled armoured ships were ordered, and five wooden line-of-battle ships were turned into ironclads of the French pattern. Eleven ironclads were thus added to the Royal Navy, making a total of fifteen under construction. The French immediately ordered ten new ironclads, bringing their total to twenty, of which three or four were ready for service, while we had only the "Warrior" completed at the end of the year 1861. Some indication of the feeling of uncertainty still prevailing here is to be found in the fact that the navy estimates for 1861–2 contained a vote for nearly a million sterling to replenish the stock of shipbuilding timber—said to be the largest vote ever passed for that service. This was subsequent to the demonstration of the great superiority of iron hulls and the commencement of ten iron-built ironclads.

The new programme showed some interesting features. A vessel of the dimensions of the "Warrior" (the "Achilles") was begun at Chatham Dockyard, marking the commencement of iron shipbuilding in these establishments. The weak features, due to unarmoured ends in the "Warrior," were removed by extending the armour from the central battery to the bow and stern, up to the height of the main deck. Steering-gear and buoyancy were thus protected, while displacement and cost were increased. Thus the "belt and battery" system came into use for first-class British ships; the French having used it for two ships built in 1859, with double-storied central batteries. Three of the new ships were made 20 feet longer than the "Warrior," about 1,500 tons greater displacement, and their cost was increased to nearly £500,000—about 25 per cent. more than that of the "Warrior." The protection of two of these was complete, as in "La Gloire;" the third was armoured on the belt and battery system. These were by far the largest and most costly war-ships of the period. Their protection and speed were about equal to that of the "Warrior." They had large sail-spreads and five masts. For a quarter of a century they remained on active service, splendid specimens of naval architecture, but indifferent fighting-machines.

Sir Edward Reed submitted plans to the Admiralty, about the period when these large vessels were building, for giving armour protection to vessels of the smaller classes, and was authorized to

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apply his idea practically. In 1863 he was appointed Chief Constructor of the Navy, and held that office for seven years, retiring in 1870. Sir Nathaniel Barnaby was responsible for the designs of Her Majesty's ships for the following fifteen years, retiring through ill-health in September, 1885, after a connection with the Constructive Department of 31 years. My work as Director of Naval Construction and Assistant Controller of the Navy extended from October 1885 to the end of January 1902. Three naval architects, therefore, have carried on the designs of British war-ships for 39 years; during which period I served at the Admiralty—with a break of 2½ years when engaged at Elswick—nearly 35 years. It is possible therefore for me to speak, with the most intimate and direct knowledge, of all that has happened in our war-ship construction since June, 1867. It will be convenient to describe what occurred during the respective periods of office of my two predecessors and myself.

Before doing so, reference must be made to events of great historical interest that occurred in 1862, on the other side of the Atlantic, where the Civil War was raging. The Confederate Government had converted a wooden frigate named the "Merrimac" into a casemated ironclad, and had armed her with powerful guns. On 8 March, 1862, she attacked the Federal fleet in Hampton Roads, sank one unarmoured vessel and captured another. All the other Federal ships present were unarmoured and at her mercy; but the work of destroying them was postponed. That evening Ericson's famous ironclad "Monitor" arrived, and next day, after a fierce fight, drove back the "Merrimac," saving her consorts. This practical demonstration of the value of the turret system, gave additional weight to the proposals, made for some years previously by Captain Cowper Coles, to add turret-ships to the Royal Navy; and very soon after two coast-defence vessels on that system were begun. One was obtained by cutting down a three-decker of 131 guns and leaving only 6 or 7 feet of freeboard, which was protected by 5½-inch armour. On this low hull, four armoured turrets were carried, each containing a heavy gun. The other ship was built of iron, and was very similar. For years after, dispute ran high as to the relative merits of the turret and broadside systems. Captain Coles was the champion of one system, Sir Edward Reed supported the broadside type for sea-going iron-clads with sail-power: eventually in 1866 two competing designs for sea-going turret-ships were approved by the Admiralty, the "Captain" designed by Captain Coles, who was associated with Messrs. Laird, and the "Monarch" designed by Sir Edward Reed.

War-Ship Building, 1863–70.

The "Bellerophon" of 1863 represents the great features of the broadside type which Sir Edward Reed introduced for sea-going ironclads. These features may be briefly summarized. The armament consisted of ten heavy guns of 9-inch calibre, each weighing 12 tons, mounted on the main deck (five on each side) in a central battery 94 feet long—or less than half the length of the battery in the "Warrior." At the bow was a short armoured battery containing two 7-inch 6½-ton guns. The 9-inch guns could perforate nearly 10 inches of iron armour at 1,000 yards range, and the 7-inch could perforate 7½ inches. This increased power of the guns was necessitated by the fact, experimentally demonstrated, that the 110-pounder Armstrong gun could not penetrate at fighting-ranges the armour of existing foreign ships. A change from breech- to muzzle-loading had been effected because of accidents which had occurred with breech-loaders. The heavier guns demanded improved mountings, and these were produced successfully; but as manual power was depended upon for loading and working, the rate of fire was slow. It will be noted that the total number of guns was reduced to about one-third of that for which the "Warrior" was designed, and in the latter the number of guns was less than one-third that in a three-decker. The belt-and-battery system was adopted in disposing the armour of the "Bellerophon," and, with the greatly shortened battery, the armoured surface was much reduced. Thickness of armour was increased to 6 inches, with special and heavy backing and steel skin, giving much greater protection than in preceding ironclads. The total weight of armour was, however, about 1,100 tons, or 120 tons more than in the "Warrior." To keep down weight of armour and hull, the length was restricted to 300 feet, and this secured vastly improved handiness and manœuvring power. Trial-speed was about the same as in the "Warrior"—a little more than 14 knots—but it required 1,000 HP. more to drive the short "Bellerophon" of 7,500 tons than the "Warrior" of nearly 9,000 tons. Sir Edward Reed preferred the greater expenditure of power, because it was associated with less first-cost and superior handiness. The "Bellerophon" was built at Chatham, and cost £356,000, exclusive of establishment charges and profit; the "Warrior," built at Blackwall by contract, cost £380,000.

One other feature of this notable vessel deserves special mention. Her hull was built on the "bracket-frame" system, with a cellular

double bottom, numerous longitudinal frames and wide-spaced transverse frames below the armour. Great lightness of construction was secured in association with ample strength, and experience has so fully justified this method of construction that it has continued to be used ever since, with many modifications, of course, as the types of ships have changed, and new materials have been employed. The "Bellerophon" has done good service; she was re-armed with breech-loading guns about twenty years after her completion, and although her name does not now appear on the Active List, she stands among vessels available for subsidiary service.

The "Hercules," completed about the end of 1868, and her successor, the "Sultan," represent the finest examples of Sir Edward Reed's broadside ships. She is 25 feet longer, and about 1,400 tons greater displacement than the "Bellerophon." Her armoured battery is only 74 feet long, containing eight 10-inch 18-ton muzzle-loading guns: the battery is shaped so as to give large horizontal arcs of training to the guns. At the bow and stern in small armoured batteries two 9-inch 12-ton guns are carried. This complete armament, therefore, consists of only 10 heavy guns, but so disposed that they command an "all-round" fire without change of place in the ship. The 18-ton guns can penetrate 11¾ inches of iron armour at 1,000 yards. The thickest armour on the sides is 9 inches, but this was limited to a very small area, the general protection being much less. The engines developed 8,500 HP. on trial, and gave a speed of 14·7 knots. Many improvements, favouring lightness and economy, had been made since 1859. The ship, although of about the same displacement as the "Warrior," and 1,400 tons less than the "Minotaur," was, because of her less length and lightness of construction, able to carry the heavy armament and 1,340 tons of armour. She proved exceptionally steady at sea, and very handy, turned in about half the time and space required by the "Minotaur," and cost about the same amount as the "Warrior," or £100,000 less than the "Minotaur."

The "Monarch," a rigged seagoing turret-ship, designed in 1866 as the rival of the ill-fated "Captain," was about the same length as the "Hercules" and of rather smaller displacement. Her side-armour had a maximum thickness of 7 inches, and her turrets (which stood above a central armoured battery) had 10-inch plating. Each turret contained two 25-ton 11-inch guns, capable of penetrating 13 inches of iron armour at 1,000 yards. The superstructures, necessary on a rigged ship, imposed serious limitations on the horizontal command of these heavy guns; and to supplement their

fire detached batteries were built at the bow and stern, containing lighter guns as in the "Hercules." This vessel cost £370,000.

In the same year (1866) an American monitor, the "Miantonomoh," crossed the Atlantic under her own steam, and paid a series of visits to European ports. She was a vessel of small size, about 250 feet long, and 14 feet draught, 4,000 tons displacement, and 9 knots speed. The freeboard was only 2 feet, and this shallow hull carried two turrets each containing two heavy guns. These turrets had 12-inch (laminated) armour, and the sides had 6-inch armour. The upper deck had 2-inch plating. Special precautions were taken for the voyage, as experience had shown that the small freeboard, while it minimized the target, involved risk of rapid foundering if water found admission. The voyage was, in fact, a *tour de force* and no evidence of real sea-going capability. In a rough sea it was not possible to work the guns. These facts were, however, overlooked, and strongly laudatory accounts of the vessel and the supposed capability of the type for general service were published. For coast and harbour services, and actions against land forts, for which this class was designed, the Monitors were admirably adapted, but for sea-work they were unsuited. I remember well a visit to the ship at Sheerness during my studentship, and the impression then made on my mind remains uneffaced.

There was, however, reason for reflection when such a vessel as the "Miantonomoh" successfully crossed the Atlantic; and the uninterrupted command of the horizon by her four heavy guns was a wonderful contrast to the hampered condition of the four turret-guns in the "Monarch"—a rigged turret-ship. No doubt this influenced the design in 1868–9, by Sir Edward Reed, of the so-called "mastless" turret ships "Devastation" and "Thunderer," which marked a new departure. These vessels were given a moderate freeboard (10 feet); their upper decks were about 3 feet above water, and were strongly plated. Above the deck was constructed an armoured "breastwork" 7 to 8 feet high, of less breadth than the ship proper. At each end of the breastwork a turret was placed, the guns being about 13 feet to 14 feet above water; the openings to the engine-room and stoke-holds, as well as the funnels, were also protected by the breastwork. A light forecastle added to the sea-going capability. The side-armour was 10 inches to 12 inches thick; the turret-armour 12 inches to 14 inches. Each turret carried two 35-ton 12-inch guns, capable of penetrating about 14½ inches of iron at 1,000 yards. There was no sail-power, and only a single mast for signalling and lifting boats. Twin-screws were fitted,

and a large coal-supply (1,700 tons) was provided. The ships were only 285 feet long, of 9,300 tons displacement, 6,600 HP., and 13¾ knots speed. They carried 2,540 tons of armour, and their heavy turret-guns had uninterrupted command of the horizon. Undoubtedly they were the most powerful fighting-machines of that day: the cost was £360,000, (exclusive of incidental charges and profit) and of this amount armour represented a very large sum.

The result of seven years' work under difficult circumstances was, therefore, an advance on the ironclads designed by Sir Edward Reed from about 7,300 to 9,300 tons in displacement, from 6 to 12 or 14 inches in armour, from 12 tons to 35 tons in guns; the number of guns had diminished from 12 to 4, and the abolition of sail-power removed hindrances to horizontal training. Besides the gun the ram remained the only weapon of attack. Twin-screws and large coal-supplies were trusted instead of sail-power for long voyages and safety at sea. Iron armour of good quality held undisputed sway. Muzzle-loading rifled guns about 16 to 18 calibres in length, with muzzle-velocities of about 1,400 feet per second, were in use, firing chilled cast-iron shot and shell. There were no locomotive torpedoes, or quick-firing guns.

Besides the ironclads, a number of unarmoured vessels were designed and built during this period. Most of these were of small size and low speed with moderate fighting-power. The only class requiring notice is that containing the swift unarmoured cruisers "Inconstant," "Raleigh," "Active" and "Volage," having speeds of 15 knots to 16·5 knots, well armed and with excellent sailing qualities. Of these the "Inconstant" was the most powerful. She was designed as a rival to the United States "Wampanoag" class, and far surpassed them. She was nearly 340 feet long, of 5,800 tons, attained 16½ knots on the measured-mile, and was armed with ten 12-ton and six 6½-ton guns. Her cost was nearly £230,000. The wood-built unarmoured screw-frigates of earlier date still continued on service, and so late as 1875 several of them were associated with the "Inconstant" and "Raleigh" in the detached training squadron.

An examination of the figures for new construction, during the 7 years Sir Edward Reed held office, shows that, from his designs were laid down twenty-five ironclads, two small armoured gun-vessels, twenty cruisers, corvettes and sloops, twenty-eight gun-vessels and gunboats for sea-service, and twenty coast-service gunboats; making a grand total of ninety-five vessels of all classes. The aggregate first-cost of these vessels, exclusive of armaments and stores, was less than 10 millions sterling.

War-Ship Building: 1870–1885.

For two years after the resignation of Sir Edward Reed, in the summer of 1870, there was a practical paralysis in British war-ship building. The office of Chief Constructor was put in Commission, the duties being performed by four gentlemen who had been Sir Edward Reed's principal assistants during the whole term of his office, and who had been trained in the same school. Sir Nathaniel Barnaby was made temporary President of this Committee, and his colleagues with himself were in all respects qualified for the work, having been indeed associated with ship-designing and construction continuously for 15 or 16 years, most of which time had been spent in connection with the Admiralty. It was no question of professional competency of the staff which prevented a permanent arrangement of the Constructive Department in 1870, when the able Chief Constructor retired, who had done so much in the ironclad reconstruction; but the sad loss of the "Captain" by capsizing under sail in the Bay of Biscay, in September, 1870, had given rise to feelings of apprehension and anxiety as to the safety of other types of ironclads. As a result a powerful Committee on Designs was appointed in 1871, with Lord Dufferin as Chairman; its members may be said to have included the most eminent representatives of science, mechanical engineering and shipbuilding, besides naval officers of high standing. Its investigations were exhaustive, and made necessary more detailed calculations for stability than had ever been made previously, as well as numerous experimental enquiries. My friend and fellow-student, the late Mr. W. John and I were placed by Sir Nathaniel Barnaby in charge of these calculations, and it became our duty to make considerable extensions of previous methods, as well as to devise new ones. Every available man capable by his training of giving assistance was placed on the work; we toiled early and late, with the result that the Scientific Sub-Committee was furnished with an unrivalled mass of information, including *data* for all types of British ships and many classes of foreign ships, amongst the latter being the American monitors.

The Reports of the Committee of Designs are classics in the literature of naval architecture, although they exist only as Blue Books. The conclusions of the Committee were, on the whole, most reassuring. It was found necessary to give increased stiffness, by means of ballast, to certain types of ironclads then completing: and to add unarmoured superstructures to secure

greater range of stability to the "Devastation" and "Thunderer." Naturally, these changes provoked controversy in various directions; the interest in these is now dead. The most important result of the enquiry in its influence on future design, was the recommendation of the Committee that the "central-citadel" type of turret-ship should be adopted, with "unarmoured ends," and the consequent preparation by Sir Nathaniel Barnaby of the design for the "Inflexible" in 1873. Probably no type of ship has been more fiercely criticized or more strongly defended. It is always desirable to keep in view the fact, that the design originated with the strongest committee ever appointed by the Admiralty, to consider the most suitable type of battleship for the Royal Navy. Sir Nathaniel Barnaby simply gave expression to these views in a design marked by much ability, and carried to a successful conclusion under difficulties of an unprecedented character.

These difficulties arose principally from the uncertainty that prevailed as to the design for the heavy guns to be mounted in the two turrets. At first it was contemplated to have 60-ton guns, and the ship was laid down on this basis. Finally, in 1874 it was decided to adopt 80-ton guns, which involved an increased weight aloft of 200 tons, and considerably modified the design, the draught and displacement having to be enlarged. There had been some previous instances of ships getting ahead of the settlement of their gun-designs, but never so serious a one as this. Unfortunately it was only the first of a long series of similar difficulties, which involved increase of cost and delays in construction of many important ships, between 1874 and 1884.

The "Inflexible" was given the standard length for battleships, 320 feet, and the standard speed, about 14 knots. Her breadth was 75 feet, which was about 20 per cent. in excess of the broadest of her predecessors. Her freeboard was less than that of the "Devastation," being intended to be 9½ feet. Her armoured citadel amidships had an extreme length of 110 feet only; and extended from 9½ feet above water to 6½ feet below. Before and abaft it, there was a strong protective deck (3-inch iron) extending to the bow and stern, so that the ship had "unarmoured ends" of great extent, which could be riddled in action by the lightest guns. To assist in preserving buoyancy and stability under these conditions, the spaces above the protective deck were minutely subdivided into watertight compartments, and were packed with cork to a considerable extent, as had been suggested by the Committee. Two turrets stood within the citadel, placed *en*

echelon to give greater horizontal command, and the superstructures were so arranged that all four guns could be fought ahead, astern, and on each broadside. These really constituted the fighting armament of the ship for battle-purposes; eight light guns for defence against torpedo-boats or light craft were mounted on the superstructures; these could not be used concurrently with the heavy guns, because of danger from the "blast."

The iron armour on the citadel had a maximum thickness of 24 inches, worked in two layers. On the turrets the armour was 16 inches and 17 inches thick, and was made of two layers of steel-faced iron (or "compound") plates. This improvement in armour was introduced after the ship was well advanced, and without sacrifice of defence; a large amount of weight was saved. The total weight of armour on sides, turrets and decks was about 3,160 tons. The 80-ton guns were 26 feet 9 inches long, and of 16 inches calibre, firing projectiles weighing 1,700 lbs. with powder-charge of 450 lbs., capable of penetrating nearly 2 feet of iron armour at 1,000 yards. The engines were on the vertical compound principle, driving twin-screws. Their greater economy enabled the coal-supply to be reduced to 1,200 tons, with equal endurance to that provided in the "Devastation," which carried 1,700 tons. The power developed on trial was 8,000 HP., the corresponding speed being nearly 14 knots. For a ship of this breadth and shallowness this was a remarkable performance; and in this particular model, experiments furnished the chief guide in estimating horse-power. As first completed she had a considerable sail-spread, being brig-rigged on two masts. This proved altogether useless, and sail-power was given up. Her displacement as completed was nearly 12,000 tons. Her construction was greatly affected by alterations in armour and armament, and occupied 7½ years. Her first cost was £812,000. One large item of additional cost was on the hydraulic apparatus absolutely essential to the working of those heavy guns, which cost nearly £50,000. The exceptional thickness and weight of the armour, and the use of steel-faced armour for the turrets, also involved much extra cost. The ship was commissioned in 1881, proved of great service next year in the bombardment of Alexandria, and continued on the Navy List until this year, when she was sold for breaking-up.

A special Committee was appointed, in 1876, to consider statements made by Sir Edward Reed, respecting the probable instability and dangerous condition of the ship if her unarmoured

ends were damaged in action. The Committee did not agree with this opinion, and the central-citadel system received further extensions. Of course, this was largely a matter of authority and opinion. Long afterwards, at the battle of the Yalu, two Chinese ironclads, in which the unarmoured ends were exaggerated, in comparison with those of the "Inflexible," while the ships were inferior to her in stiffness and in arrangements for maintaining buoyancy and stability when the ends were riddled, not merely bore the brunt of the fighting, but actually followed up the Japanese fleet at the close of the day. Admiral Ito, who commanded the Japanese that day, had done all he desired, by the practical destruction of the Chinese naval force, and took no extra risks. This fact appears to support the opinion of the Committee and the action of the Admiralty at that time.

The last two-rigged broadside ironclads of the Royal Navy were also laid down in 1873 from Sir Nathaniel Barnaby's designs. It it unnecessary to describe them, but it may be of interest to state that in the "Temeraire" a central battery was associated with two barbette towers, protected by 8-inch and 10-inch armour, each containing a 25-ton gun mounted on the "disappearing" principle, on a revolving turntable. Hydraulic power was utilized for working these guns: a system devised by the late Mr. G. W. Rendel, and developed by Messrs. Armstrong, thus received one of its first and most notable applications. Mr. Rendel grasped the principle that although manual power could be, and was applied successfully, to working very heavy guns, the processes were necessarily slow, and the numbers of men large. To his genius we owe the introduction of ingenious mechanisms saving time and labour, reducing crews, and greatly increasing rates of fire. Since he initiated the system it has been greatly extended, and electrical, steam and pneumatic power have been utilized; but in the Royal Navy hydraulic power still holds the first place for heavy guns.

The principle of "concentration" in armour and armament received its extreme illustration in the "Inflexible," and was not abandoned for some years. But it had its weaknesses; and when the French started their new naval programme in 1872, after the conclusion of the war with Germany, they designed battle-ships which were intended to have superior fighting qualities at sea. The moderate freeboard of our turret-ships and the small height of turret-guns above water resulted, especially in ships armed *en echelon*, in serious interference with fighting efficiency on the open sea in rough water, although it was well adapted for ordinary Medi-

terranean weather or smooth water. The French, with their usual clearsightedness, designed high-sided ships with a few heavy guns mounted high above water in armoured barbettes; and associated with these a large number of light guns, mounted between decks on the broadside, without armour protection. In short, they combined principal and secondary armaments, in a type which had undoubted claims to greater efficiency for sea-fighting in rough water than our turret-ships could claim. The light guns also gave the power of rapid fire in combination with the necessarily slower fire of the heavy guns; whereas in our ships the great horizontal command of the turret-guns made it practically impossible to have a powerful and efficient secondary armament. In armour-protection our ships were immensely superior, as the French were content with a narrow water-line belt of armour running from bow to stern, and rising only 2 feet to 3 feet above the load-line, a protective deck closing in the hold-space at the level of the top of the belt. Above this the sides were unarmoured.

This action on the part of French designers necessarily caused a change of practice here. In 1879 the first vessel of the "Admiral" class was designed, her construction being commenced in 1880. There were differences in detail between the ships of this class, but the "Anson," designed in 1882–3 and completed in 1889 will serve as an example and illustrate the state of warship-building twenty years ago. The vessel is built of mild steel, is 330 feet long, 68½ feet broad, and has a belt of armour 7½ feet deep extending for 150 feet of the length amidships. As designed, it was intended to be 2½ feet above the load water-line and to extend 5 feet below; the completed ship was nearly a foot deeper than designed, owing to additions made during construction. At the ends of the belt, there are armoured transverse bulkheads crossing the ship: before and abaft the belt there is an underwater steel protective deck 3 inches thick; while the lower deck, above the belt, is covered with 2½ inches of steel plating. The belt armour has a maximum thickness of 18 inches, and is "compound." The unarmoured ends are subdivided minutely: and are assigned to the storage of coal, water and stores, but there is no cork packing. Above the belt the sides are cellular and subdivided, but not armoured.

The vessel is armed with four 13·5-inch breech-loading 67-ton guns, 36 feet long, capable of penetrating more than 27 inches of wrought-iron armour at 1,000 yards, the projectiles weighing 1,250 lbs. and the powder-charge 520 lbs. These guns are mounted in pairs on turntables in armoured barbettes at a height of over 20 feet

above water, can all be fought on either broadside, and command arcs of 270 degrees in horizontal training across the bow and stern. The armour on the barbettes is 12-inch and 14-inch, steel-faced. Hydraulic machinery is employed for loading and working the guns, and although they are mounted *en barbette*, the loading operations are protected by thick armour. On the broadside between the barbettes are mounted six 6-inch breech-loading guns, about 15 feet above water, and in addition the ship carries twelve 6-pounder and ten 3-pounder quick-firing guns. The secondary armament has shield protection but no armour. There is also an armament of Whitehead locomotive torpedoes with four above-water discharging-tubes; the ship is internally lit by electricity. Vertical compound-engines drive twin-screws with forced draught; 11,500 HP. has been developed for short periods and a speed of 17 knots has been attained; with natural draught the figures are 7,500 HP. and 15·7 knots. There is no sail-power, but 1,200 tons of coal are carried, and the coal-endurance is large, as the vessels are easily driven at cruising-speeds. Although 10 feet broader and 55 feet shorter than the "Warrior," and of about 800 tons greater displacement, the "Admiral" class are driven as easily as the "Warrior" was up to her maximum speed of 14·35 knots, and they have, besides, the power of reaching nearly 16 knots without serious "forcing" of the boilers. This is due partly to a good form, and partly to greater efficiency of the more modern twin-screw engine. The bunker-capacity is only 60 per cent. greater in the "Anson," but the coal-endurance at 10 knots is three times as great as the "Warrior's," as a result of reduced consumption.

It will be observed that after twenty years of adherence to a speed of about 14 knots for iron-clad battleships a considerable step was made in the "Admiral" class. Further, her armament consists entirely of breech-loading guns, the muzzle-loading system having been abandoned about 1880, and guns longer in relation to calibre having been introduced as the result of the valuable experiments on slow-burning powders carried out by Sir Andrew Noble. Higher muzzle-velocities and greater penetrative power were thus secured; the 67-ton breech-loading gun was endowed with an energy over 10 per cent. in excess of that possessed by the 80-ton muzzle-loading gun, and can perforate about 17½ per cent. greater thickness of armour. The 6-inch guns first mounted, weighing 5 tons, had an energy exceeding that of the 6½-ton muzzle-loader by more than 60 per cent., and could penetrate nearly 11 inches of iron at 1,000 yards, as against 7¼ inches. Another striking feature of advance

is the introduction of locomotive torpedoes, while the use of quick-firing guns, 6-pounders and 3-pounders, although primarily due to the desire to provide defence against torpedo-boat attacks, was also an important element of offence in action, against ships in which armour protection was limited in area while many of their light guns were placed in unprotected positions. The system of armour, in principle, resembled the French, so far as the narrow water-line belt was concerned: only the French adhered to a belt for the whole length, whereas less than half the length was armoured in the "Admiral" class. In both types there was a frank surrender of the protection of stability by armour, for all but small angles of inclination; the Admiralty view was that, when such narrow belts were accepted, there was no sufficient reason for carrying them on to the extremities. This view was disputed, but unarmoured ends continued to be adopted in British armoured ships as the best possible compromise, up to quite recent designs; this decision having been affirmed by many Boards of Admiralty after full consideration. The offensive powers had been greatly increased, while the defensive had been relatively diminished, so far as armoured area was concerned; although the use of hard steel-faced iron armour, instead of soft iron, had very greatly increased resistance to penetration by the chilled-iron projectiles then used. The "Anson" cost about £662,000 or £150,000 less than the "Inflexible." Both ships were built in the Royal Dockyards.

Incidentally, it is interesting to note that Whitehead's invention of the locomotive torpedo, not merely added to the offensive powers of ships, but brought into existence the torpedo-boat. The first of these was built by Thornycroft in 1873 for the Norwegian Navy, and in 1877 the first British torpedo-boat, the "Lightning," was built by the same firm. She was 85 feet long and of 18 knots to 19 knots maximum speed, with a displacement of 27 tons. No one then anticipated to what an extent the torpedo flotilla would grow in a quarter of a century, or what varieties of types it would include, thanks to the efforts of naval designers and the demands of rival Navies.

The "Victoria" and "Sanspareil," of 1885, were Sir Nathaniel Barnaby's last battle-ships, and, in many respects, noteworthy. They had low freeboard forward and a single turret, containing two 110-ton breech-loading guns, with their axes about 16 feet above water. Abaft the turret the hull was built a storey higher; and in this portion of the ship were mounted twelve 6-inch guns, while, on the upper deck aft, one 10-inch gun was carried as a

stern-chaser, with shield-protection only. The hull armour was arranged similarly to the "Anson's," the belt being 162 feet long, and the maximum thickness 18 inches, of "compound" quality. The turret base was protected by a redoubt, also 18 inches thick: the turret armour was 17-inch. The 6-inch guns had 3-inch steel armour as their protection. Altogether, nearly 3,000 tons of armour were carried. Triple-expansion engines were fitted, and the speed was about a quarter of a knot higher than that of the "Anson." The cost was £781,000; as the ships were built by contract this sum included establishment charges and profit.

On the side of cruisers and small vessels very moderate advances were made between 1870 and 1882. In a few instances events of note occurred.

The construction of the steel dispatch-vessels "Iris" and "Mercury," in 1875, stands out prominently as a land-mark in modern ship-building, both because of the change in material, and the high speed attained. The vessels were only 300 feet long and of 3,700 tons displacement, but they attained 18 knots. Their fighting value was small, their armaments light, but their coal-supplies were large, and they were the "Scouts" of that period, but they were never repeated. They cost about £225,000.

In 1876 the "partially protected" cruisers of the "Comus" class were built, with good armament, and a protective steel deck over engines and boilers. Their moderate speed (13 knots) made them unsuited for fleet work; indeed they were designed for independent service on distant stations, had single screws, and good sail-power. They have done excellent service. In 1880 the "Leander" class was begun. These were very useful vessels, about 600 tons larger than the "Iris," with 16½ knots speed and coal supplies of 1,000 tons. They were partially protected, like the "Comus," and much more powerfully armed, carrying ten 6-inch breech-loading guns, and a number of small quick-firers. They were fitted with a good auxiliary spread of sail, to assist in making long sea-passages. The cost (by contract) was about £190,000. These were exceedingly useful vessels, but the restriction of the protective deck was objectionable, and in 1882 the "Mersey" class was designed with a complete protective steel deck extending throughout the length. These cruisers were of nearly the same dimensions as the "Leander" class, but had no sail-power; and the adoption of forced draught, with quicker-running engines, economized weight, so that it was possible to add two 8-inch breech-loading guns to the armament carried by the "Leander" class. Four of these vessels were built. The maximum speed was

about 17 knots with forced draught, and 15½ knots with natural draught. The cost was about £210,000, and they were built in the Dockyards.

Concurrently with their construction, protected cruisers were building on the Tyne for Chili and Italy (the "Esmeralda" and "Giovanni Bausan"). While the principal features of the vessels bore considerable resemblance to the "Mersey" class there were important differences. Mr. G. W. Rendel was largely responsible for the designs, and the armaments included 10-inch breech-loading bow- and stern-chase guns. The protective decks were, however, less in thickness and differently arranged than the corresponding features in the "Mersey" class, and the coal-stowage was not so great.

Later on, in 1883–4, I designed and built at Elswick, for the Japanese Navy, two protected cruisers exceeding all these vessels in speed and armament, while resembling the "Mersey" class in protection. These vessels were completed in 1885, and have seen much war-service since. The "Naniwa" had the first fighting in the war with China—both ships were at the battle of the Yalu—and Admiral Ito, who commanded, wrote to me after the battle to express his complete satisfaction with their performance then and throughout the war. These two vessels have been almost continuously at work since their construction, and Messrs. Hawthorn, Leslie & Co., who made the engines, must be well content with their work.

Armoured cruisers are distinguished from protected cruisers, in having vertical side-armour and protective decks instead of curved decks only from side to side. The earlier examples are better described as "belted" cruisers, the vertical armour covering only a small area. The "Imperieuse" and "Warspite," designed in 1881, are now included in this class, although they were at first regarded rather as second-class battle-ships. The "Orlando" class, designed by Sir Nathaniel Barnaby in 1885, are later examples. They are 300 feet long, 56 feet broad, of 5,600 tons, and 18 knots speed with forced draught. Their side-armour is in a very narrow belt about 184 feet long, and 5½ feet wide, the thickness being 10 inches. The deck above the belt is of 2-inch steel, and at the ends 3-inch. There is a good armament with shield protection carried on the upper deck, including two 9·2-inch, ten 6-inch and sixteen 6-pounders and 3-pounders. The vessels have been continuously employed, and have excellent reputations for behaviour at sea. Although now out-classed by modern cruisers, they were admirable vessels in their day.

One other vessel designed by Sir Nathaniel Barnaby ought to be noticed. The "Polyphemus," torpedo-ram, was begun in 1878, completed in 1882, and stands alone. She was 240 feet long, 40 feet broad, of 2,640 tons displacement, 5,500 HP., and 18 knots maximum speed. Her hull proper rose only a few feet above water and was strongly curved, being protected by Whitworth steel armour. A light forecastle and poop were built to assist in maintaining high speed and to improve sea-going qualities. All openings into the interior were trunked up to a flying deck, and protected by armour. The gun-armament consisted of six 6-pounder quick-firing guns carried on the flying-deck; and there were five torpedo-discharging tubes, four on the broadside and one at the bow, all of course submerged. The ram-bow was of immense strength. Great handiness was secured by twin-screws, powerful rudder, and unusual form. Detachable ballast was carried, so that in case compartments were bilged the buoyancy and trim might be restored by letting go blocks of ballast. The sub-division was minute. Light and ventilation were artificial throughout, and she proved a healthy ship. She made cruises in the Atlantic, and the passage out and home to the Mediterranean. Apart from the failure of the locomotive-boilers the vessel was a complete success. Mr. Watts, now Director of Naval Construction, was in charge of details of the design, and watched the construction throughout at Chatham. I had charge under Sir Nathaniel Barnaby at the Admiralty. No pains were spared to secure the results reached, and all that was promised was fulfilled. But my personal opinion always was, that this type was purely experimental, and not likely to be generally adopted. The practical absence of gun-armament and the limited sea-keeping qualities were unsatisfactory features. The net cost was £226,000 and she took four years to build.

From 1870 to 1885 Sir Nathaniel Barnaby was responsible for the designs of twenty-eight iron-clads, six armoured cruisers ("Orlando" class), nine protected and eighteen partially protected cruisers, and one hundred and twenty-nine unarmoured armed vessels of all classes: a grand total of one hundred and ninety. The aggregate first cost of these vessels was about 27 millions sterling. When he resigned, in consequence of ill-health, the Northbrook Programme had been recently commenced, and the two battle-ships and six armoured cruisers included under it were in an early stage of construction. He had well-earned the rest which he has since enjoyed.

War-Ship Building: 1885–1903.

It is with considerable diffidence that I approach this period of naval construction and speak of the character and magnitude of the extensions made in the Royal Navy, because there is a danger of appearing to appraise or commend work in which, from my official position, I have taken a prominent part. Trusting to your kindness an attempt will be made, however, to set forth the essential facts briefly. On other occasions I have dealt with sections of the subject, and it will be my endeavour to avoid repetition of what may be read elsewhere.

Many new departures have been made in the armour, armament, types, speeds, and propelling-apparatus of war-ships during this period. Mechanical appliances have been multiplied, and electrical power has been largely extended. The task of the naval architect has been one of increasing difficulty and complexity.

Recent Improvements in Guns and Mountings.

Naval gunnery has been revolutionized. Guns have been greatly increased in length and weight in proportion to their calibres, their structures have been improved, better propellants have been introduced, and higher velocities and energies have been obtained. Forty to fifty calibres are now common lengths, 2,500 to 3,000 feet per second are treated as ordinary muzzle velocities, and 3,500 to 4,000 feet per second are contemplated. The 12-inch gun which, as a muzzle-loader, weighed 35 tons and had 13·5 calibres length, with about 1,400 feet per second muzzle velocity and 9,500 foot-tons of energy, has given place to a breech-loader of the same calibre weighing 50 tons, 40 calibres in length with 2,480 feet per second muzzle velocity and 36,000 foot-tons of energy. The earlier gun could penetrate 14·5 inches of iron at 1,000 yards, the latter nearly twice that thickness at 3,000 yards. In accuracy and range of course the later gun is immensely superior.

The earlier 6-inch breech-loading gun weighed about 5 tons, was 26 calibres in length, had a muzzle velocity of about 1,900 feet per second, and energy of about 2,500 foot-tons, penetrating about 10½ inches of iron at 1,000 yards. The present 6-inch gun weighs about 7·5 tons, is 45 calibres in length, has a muzzle velocity of 2,530 feet per second, an energy of 4,450 foot-tons, and can penetrate 10·4 inches of iron at 3,000 yards. These are triumphs for the gun-maker, but raise many fresh problems for the naval architect.

Rapidity in rate of loading has been greatly increased. The introduction of the larger types of quick-firing guns, 4·7-inch and 6-inch, is another instance of the experimental research and enterprise of Messrs. Armstrong. It began a new movement in 1886, and the Admiralty gave it great encouragement. Other firms of gun-makers have done much to develop rapid loading, and, by means of improved breech-arrangements, gun-mountings, and appliances for handling ammunition, very remarkable results have been obtained, not merely on contractors' trials but on service. The 12-inch gun has been fired un-aimed at contractors' trials with intervals of 30 seconds to 50 seconds between successive rounds, and at prize-firing at a target at intervals of 1 minute, with about 68 per cent. of hits. The 6-inch guns have been fired at a target at the rate of nearly 7 rounds per minute, the percentage of hits being over 70. The 9·2-inch gun, with its 380-lb. projectile and 166-lb. charge, has been fired at the rate of 3 rounds per minute.

With this greater rapidity of fire comes the question of larger supplies of ammunition, and greater weight and space for storage. Appliances for the rapid transport of ammunition also become essential; as, in defect of adequate supplies, there can be no utilization of the improvements in guns and mountings. In many instances, one has seen elaborate systems for transport, either altogether unprotected, or inadequately protected at some vital part. No problem in connection with armaments requires more care than that of adequate and protected supplies of ammunition. Many comparisons between the offensive powers of different ships have ignored this feature, and have consequently been misleading or incomplete. In some instances the numbers of men provided for in designs have been entirely inadequate in proportion to the armament. In other cases the appliances for transport of ammunition have been most imperfect, yet credit has been taken for rates of loading and firing possible only under the most efficient conditions.

These changes in guns and mountings have greatly influenced the rate of construction for war-ships, and seriously affected cost as well as progress. The complaint is not a new one, but it is no less true. So long a time is frequently occupied by Committees and sub-Committees in working out details of new guns and ammunition before actual patterns are finally settled and manufacture begins, that in many instances in my experience, ships have had to wait for guns, and in others to have considerable modifications made in consequence of changes in gun-designs.

Experience in the Royal Navy between 1879 and 1885 was most trying to those of us who had to be responsible for new designs. In one instance, important ironclads were laid down and considerably advanced before the principal armament was decided upon. The design was based on provisional estimates for weights of guns and ammunition, and for muzzle velocities. These provisional estimates were so far departed from, however, in the final design for the guns, that the draught and depth of the ships had to be increased a foot, and the armour lifted the same amount. Fortunately the discovery was made at a time when the work was not too far advanced to permit of the alteration being made at moderate cost, but rapid progress with the ships was impossible under such conditions, confidence in the results was shaken, and the cost was considerably increased. The case of the "Inflexible," designed for 60-ton guns, and then re-designed for 80-ton guns, has been mentioned. For this reason 13·5-inch guns were used in the "Royal Sovereign" class of 1889, although it would have been preferred then to have adopted 12-inch guns, had a satisfactory design been available. I represented to the Board that experience proved that rapid and economical construction, as well as fulfilment of the intentions of the design, was impossible unless the gun-design was settled in advance. In 1888 I designed the "Blake" and "Blenheim" for 6-inch quick-firing guns; but the time taken in final approval of the patterns for guns and ammunitions prevented the ship from having them fitted before she left for service in 1892. At that date too I had to recommend the adoption of 10-inch guns in the "Renown," chiefly because a satisfactory design for 12-inch guns was not available at that date, although the need for such a design had been made known three years earlier. In more recent times there has been a distinct improvement, and I have known cases where guns have been waiting for ships. But there appears to be some possibility even now of improvement in the matter of settling new types of guns, and, in my judgment, that settlement should always be arrived at for guns, ammunition and mountings before the work of building a modern war-ship is begun, if rapidity and economy are to be ensured.

Recent Improvements in Armour and Projectiles.

The manufacture of armour as well as of guns has been greatly improved. Chrome-steel projectiles were introduced in 1886 and proved capable of piercing thicknesses of hard-faced armour that

were impenetrable with chilled cast-iron. In 1887 I suggested a fresh series of experiments with guns of high velocity against steel and steel-faced armour-plates. All the leading steel-makers were invited to submit experimental plates, which the Admiralty engaged to pay for and to test. Out of these experiments came good results, both as regards the production of superior steel armour, and the enlargement of our sources of supply, which was essential to the Programmes of Construction then in contemplation. Nickel-steel armour was introduced at this time and tested here, although it is often asserted that the material was introduced first in other countries. We were, of course, always ready to avail ourselves of all improvements wherever they originated, so long as the manufacture was conducted in this country, and actual experiment proved the value of the new processes. "Harveyed" armour was thus introduced in 1893, and Krupp's improvements thereon were made use of three years later. We can claim to have always kept to the front in regard to improvements of this nature, so far as their practical use is concerned.

It is essential that the designer of war-ships should have a good knowledge of metallurgical processes, and be in close touch with manufacture. Throughout my term of office the responsibility for supervision of the manufacture of armour-plates and all steel material used in shipbuilding rested upon me as Director of Naval Construction; and had it been otherwise equal progress would not have been made.

Armour of the quality now adopted for war-ships is equal in resisting-power to more than twice its thickness of wrought iron, besides being greatly superior to the qualities of steel and steel-faced armour in use fourteen years ago. Hence it has been found possible with a given weight of armour to secure effective protection for much larger surfaces, and the shrinkage of armoured areas which went on up to 1885 has given place to a considerable increase of protected area. This was undoubtedly desirable, in view of the destructive effects of high explosives, such as "melinite" and "lyddite," introduced about fifteen years ago. At the same time it is quite possible, unless the proper quality of armour is used in sufficient thicknesses, to devote considerable weights and cost to protection without adequate advantage; in fact, as is well known, against moderate thicknesses of soft steel armour it is far preferable to use chilled cast-iron, or special forms of steel projectiles, instead of high-explosive shells. It is always true that the attack is more flexible than the defence, since the character of projectiles and "bursters" can be readily modified; whereas armour, when once fitted, is difficult to deal with or to modify.

At present the problem is how to increase the efficiency of armour-piercing projectiles against armour in which chromium, as well as nickel, is alloyed with steel and subjected to special treatment. The subject of "capped" projectiles was treated last session, in a Paper[1] read by Mr. D. Carnegie, and the discussion upon it showed that very diverse opinions are held as to the gain from the use of caps. It would be absurd to suppose, however, that finality has been reached, either in armour or projectiles. There has been a great increase in the possible output of armour in this country during the last five years, and the competition is so keen that further improvements are certain to be effected. It is strange to recollect that in 1887–8 high authorities were disposed to think that armoured ships would cease to be built. Instead, the use of armour has been greatly extended in cruisers as well as in battle-ships, and the two classes have drawn nearer than ever, differing only in the nature of their bow- and stern-chase guns and in the thicknesses of their armour.

Recent Programmes of Naval Construction.

Before giving particulars of a few typical ships of the period under review, it may be proper to point out that in one important respect our naval shipbuilding has differed in character from that of earlier periods. From 1888 onward we have had a succession of large programmes of construction, embracing large numbers of ships of all types required to constitute a modern fleet, with its great variety of services. Apart from any official knowledge, it must be obvious to anyone familiar with our Navy Estimates that formerly they were framed rather on the basis of immediate requirements than on any comprehensive scheme. A few battle-ships were built at a time, and usually only two or three from one design. There was no homogeneity in our fleet, and the armaments were so different in character and disposition, that there was no possibility of that joint and harmonious action, which can be secured when the units of a fleet are similar. Again, there was no simultaneous provision of all the types required to make up a fleet—cruisers, scouts, and other vessels. As has been shown, the cruiser classes were for a long period almost neglected, or only spasmodically dealt with, attention being rather concentrated on battle-ships. All this has been changed.

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[1] "The Manufacture and Efficiency of Armour-Piercing Projectiles," by D. Carnegie, Assoc. M. Inst. C.E. Minutes of Proceedings, Inst. C.E., vol. cliii. p. 1

The Naval Defence Act of 1889 was framed to provide a modern fleet, complete in all its parts, and did so at a cost of about 22½ millions for seventy ships. Since that date there has been a succession of programmes, each of a progressive nature, and equally effective with the Naval Defence Act scheme, although not embodied in an Act of Parliament or published. My conviction is that the preferable course, provided there is a definite programme, is to refrain from making it known, as possible rivals are then left in ignorance of our intentions; and, with our enormous shipbuilding and gun-making resources, we can always ensure keeping the lead in finished ships, even if we start somewhat later. I am aware of the progress made abroad in accelerating construction, and that statements have been made that our former superiority has disappeared, or nearly so. But these statements are not well-founded, and anyone who cares to enquire can ascertain that this is so. The latest illustration of the contrary view is to be found in the lead we have taken in recent types of armoured cruisers, although we did not start until foreign types had been settled and construction had begun. Waiting, under these circumstances, is obviously a proper policy in order to ensure superiority for our vessels of a particular class, always provided that a start is made in proper time for us to secure earlier completion.

The change of practice in regard to our programmes of construction has arisen from various causes. One of the most influential has been the able Report drawn up in 1888 by three distinguished admirals who were appointed as a committee to report on the naval manoeuvres of 1888. Amongst them was our Honorary Member, Admiral of the Fleet Sir Frederick Richards, G.C.B. The report went far beyond the intentions and expectations of the Admiralty, who appointed the Committee; and the general summary with which it concludes is a composition which should be studied by all charged with the conduct of our naval affairs. It undoubtedly had weight, not merely in connection with the framing of the Naval Defence Act, but in greatly influencing the subsequent naval programmes of Lord Spencer and Lord Goschen. Sir Frederick Richards was for a long period the chief naval member of the Board of Admiralty, and in office did not shrink from giving effect to the principles he had laid down when in a less responsible position. His political chiefs have testified publicly to the great services he has rendered, and I have felt moved, on this occasion, to bear my testimony, resting, as it does, upon a close official connection of long standing.

The task of framing a naval programme is no light one, and

after many experiences of the kind, I may say that it became no easier by repetition. The "making of a modern fleet," as I have said elsewhere, involves the following principal steps—

1. There must be a determination, by competent authority, of the types of ships to be built, and the numbers in each type. This involves a decision respecting the offensive and defensive powers, the speed, and coal supply to be provided in each type.

2. Designs must be prepared fulfilling the specified conditions.

3. Estimates of total cost, and of the incidence of expenditure on each year of the period of construction, must be made.

4. The orders for ships, machinery, and armaments must be carefully allocated, so that the work of construction may be completed within the stipulated period.

The first step is undoubtedly the most important. In default of actual experience in warfare with modern ships, there are necessarily wide divergences of opinion regarding the relative values of different types. There are advocates of large ships possessing great individual fighting-power; of small swift ships built in large numbers for a given expenditure; of torpedo vessels pure and simple; of armoured rams; and of many other systems of construction. Very often a particular course is advocated as suitable for exclusive adoption; in disregard of the principle, sanctioned by the universal experience of all navies, that in a fleet there must be many types specialized and adapted to different services, mutually supplementing and supporting one another.

The Board of Admiralty is the final and responsible authority, which has to decide what qualities of offence, defence, speed, and power of keeping the sea shall be embodied in the design of each of His Majesty's ships. This task naturally devolves principally upon the naval members, whose high rank in the service, long experience afloat, and special information make them peculiarly qualified for their duty when acting as a "Committee on Designs." In dealing with the numerous and difficult problems presented to them when framing a new programme, the Admiralty has many advantages. Under its direction is the largest war-fleet in the world. From the naval service afloat, valuable reports and suggestions are constantly being received, embracing particulars of the performances of ships in commission, proposals for improvements in future designs, records of experiments and results of experience. Full information is available at the Admiralty respecting the latest progress in naval *matériel* affecting ordnance, ammunition, torpedoes, armour and machinery of all kinds. Progress made in our great mercantile marine suggests and assists progress in the

war-fleet. Full knowledge of what is being done abroad in the construction and armament of ships is available, and is obviously essential to a wise selection of the types to be built for the Royal Navy. The responsibility for decision and action always rests with the Admiralty.

So far as one can judge, the three classes required to deal with these problems efficiently must be:—the politician, who knows the policy of the Cabinet of which he is a member; the naval officer, who is responsible for the strategy and tactics of the fleet; and the naval architect who designs the ships to fulfil the conditions laid down. Each has his distinct duty and responsibility; and the naval officer must not trench upon the province of the naval architect, nor the latter pose as an authority on naval strategy or tactics. Each may know much of the other's special department, and there may be mutual assistance, but their duties are distinct. The amateur naval architect is as objectionable and dangerous as the amateur strategist. In my long experience at the Admiralty my relations with naval officers have always been most cordial, and my responsibility has been uniformly respected; so that I can venture to say what has been said.

Under present conditions, with great public interest attaching to all matters connected with the Royal Navy, there is no small danger of these fundamental considerations being overlooked or ignored. That product of modern times, the "naval expert," has every confidence in his capability to settle policy, strategy, tactics, and ship-design. His criticisms are sweeping, and his conclusions and proposals must not be questioned. If he has a weakness it is a belief in the doctrine that "these things are done better" abroad, and a conviction that entry into the public service impairs the ability of any man. It is one of the conditions which a public servant has to accept, that anonymous writers of this class shall deal with his professional work, and inform the public of its shortcomings. Sometimes one is disposed to "turn and rend" the offender, especially if he drops the veil of anonymity; but, on the whole, silence is undoubtedly the wiser course.

Typical War-Ships, 1885–1902.

As typical battle-ships of the period now under review the "Royal Sovereign" class of 1889 may first be taken. They were the largest and fastest British battle-ships built up to that time, 380 feet in length, 75 feet broad, of 14,150 tons displacement,

16½ knots speed under natural draught, and about 17½ knots under forced draught. The armour-belt extends for 250 feet of the length and is 8½ feet deep; the maximum thickness is 18 inches. Between the belt and the main deck a "strake" of armour, 4 inches thick, rises to the height of 9½ feet above water, over a length of 145 feet, and is then carried obliquely across to the armoured barbettes by bulk-heads protecting a total length of 170 feet. The deck at the top of the armour-belt is covered by steel plating 2½ inches thick. The ends of the belt are completed by armoured bulkheads, crossing the ship. Before and abaft the belt there is an under-water protective steel deck, 3 inches thick. These unarmoured ends are subdivided and appropriated for stores, etc., as already described for earlier vessels; but no coal is carried there. The barbettes maintain their full size down to the lower deck at the top of the belt; departing in this respect from precedent and possessing unusual strength with 17-inch armour. The total weight of armour is 4,500 tons. There are two 67-ton guns in each barbette. Between the barbettes ten 6-inch quick-firing guns are mounted, four on the main deck in armoured casemates, and six on the upper deck with shields. Recently, casemates have been added for these upper-deck guns. In addition there are twenty-eight 6-pounders and 3-pounders. Seven torpedo-tubes are fitted, two submerged and five above water. The vessels have high freeboard throughout, and carry their 13·5-inch guns at a great height above water. These guns are mounted *en barbette* as in the "Admiral" class. The "Royal Sovereign" cost £760,000, or £50,000 less than the "Inflexible." It has been explained that 12-inch guns would have been adopted had a satisfactory type been available.

The "Implacable" of 1896 represents a modification in some particulars of the "Majestic" class of 1894. She is 400 feet long, 75 feet wide, and of 15,000 tons displacement. Water-tube boilers supply 15,000 HP. at natural draught, and give a speed of 18 knots. The armour is of Krupp quality, and is disposed differently from that of the "Royal Sovereign." There is no thick belt; but a citadel, with armour uniformly 9 inches thick, extends vertically from the main deck down to about 5½ feet below water, and longitudinally for nearly two-thirds of the length, the ends wrapping round the bases of the barbettes. The protective decks within the citadel are two in number, one at the main deck and the other at the lower deck; the edges of the lower deck are curved down to meet the lower edge of the side-armour. Before and abaft the barbettes the sides are protected by thin armour in the

region of the water-line aft, and up to the main deck forward. The armour on the barbettes is 12-inch, but its superior quality makes the defence equal to that on the "Royal Sovereign," which is "compound." The armament includes four 12-inch guns, protected by strong armoured shields, and twelve 6-inch, all of recent patterns, besides sixteen 12-pounders and six 3-pounders. The mountings for the 12-inch guns are greatly superior to those of the 13·5-inch guns of the "Royal Sovereign"; and instead of loading only in fixed positions, the heavy guns of the "Implacable" can be loaded in any position and about twice as rapidly. All the 6-inch guns are protected by separate armoured casemates. The cost is about £1,100,000.

The "King Edward VII." class, my last design of battle-ships, dates from 1901. Their length is 425 feet, breadth 78 feet, displacement 16,350 tons. They have machinery and boilers developing 18,000 HP.; the estimated speed is 18·5 knots. They have a citadel resembling that of the "Implacable," with 9-inch armour at the water-line, but from the lower to the main deck the thickness is 8 inches. Instead of wrapping round the base of the fore barbette with the citadel armour, it is continued forward on the sides, and gradually diminished in thickness, the minimum at the stem being 3 inches. At the after end the side-armour resembles that of the "Implacable" class. There are two protective decks as on the "Implacable." The total weight of armour and backing is about 4,800 tons. The barbettes are similar to those of the "Implacable," and each contains two 12-inch guns mounted on turn-tables with strong armoured shields. On the main deck between the barbettes there is a central battery with 7-inch armour on its sides, containing ten 6-inch quick-firing guns. On the upper deck are four 9·2-inch 24-ton guns mounted in four separate revolving armoured shields or "gun-houses." The use of these heavy guns in association with 12-inch guns is a novel feature, and results from the fact that, as the armour protection given to secondary armaments in recent battle-ships is now superior to the penetrating-power of 6-inch quick-firing guns at fighting-ranges, it is necessary to have more powerful guns. The adoption of a central battery instead of casemates is a return to one of the oldest plans for ironclads, as will be obvious from preceding descriptions. In this design casemates were not suitable, as the 6-inch guns are necessarily placed closer together than has been usual in our battle-ships, because of the introduction of the 9·2-inch guns. It was, therefore, more economical of weight and cost of armour to adopt a battery instead of separate casemates; and a further

saving results from the absence of the strong protective main deck which is not needed within the battery. On these grounds I recommended the adoption of a battery; but the new departure does not involve any change of view as to the utility of casemates under the circumstances in which they have been used in earlier ships. It simply indicates the recognition of the principle that stereotyped methods are to be avoided, each problem being dealt with as may seem best. The battery is constructed with strong "traverse" bulkheads between the guns; for it is clear that the concentration of many guns and their crews in one enclosure introduces certain risks, especially if the shells from heavy guns penetrate into the battery. There are eight vessels of this class building, representing in the aggregate about 10½ to 11 millions sterling, exclusive of armaments. They are the largest battle-ships yet added to the Navy, but are of very moderate size as compared with a large number of existing merchant-ships, for which details have been given. It may be of interest to give details of the estimated cost of the "King Edward VII." The hull and armour are to cost about £820,000; about half that sum representing the value of the armour, and £250,000 the cost of labour. Propelling and auxiliary machinery are estimated at £217,000; hydraulic gun-mountings and mechanisms at £186,000; other gun-mountings at £21,000, and torpedo-tubes at £7,800. Incidental charges are put at £86,000, making a grand total of £1,337,000. The guns will cost nearly £90,000; ammunition and reserves are additional. Fully equipped each ship of the class represents over 1½ million sterling —a great responsibility for her commanding officer.

TYPICAL ARMOURED CRUISERS, 1897–1903.

Armoured cruisers of the modern type date in the Royal Navy from 1897, when the "Cressy" class was designed. They resemble battle-ships in their secondary armament and the distribution of their hull armour; but they carry nothing heavier than two 9·2-inch bow- and stern-chase guns, instead of the four 12-inch guns, and have no strong armoured barbettes.

The vessels of the "Drake" class are the largest of the type yet built. They were designed in 1898–99, and there are four of them. Their length is 500 feet, breadth 71 feet, displacement 14,100 tons, side-armour 6-inch (maximum), casemates and shields 5-inch. Water-tube boilers give 30,000 HP. with natural draught, and the corresponding speed is 24 knots. The armament includes two 9·2-inch

guns in armoured revolving shields, one on the forecastle and one on the upper deck aft; sixteen 6-inch in casemates, eight on the upper deck, and eight on the main deck; fourteen 12-pounders, and three 3-pounders. The cost is rather more than one million sterling.

The "Cressy" class is smaller: 440 feet long and 12,000 tons, wood-sheathed and coppered. They steam 21½ knots with natural draught. In protection they resemble the "Drake" class, and in armament are a little inferior, carrying four 6-inch and four 12-pounders less than the "Drake." The cost is about £750,000.

The "County" class is a numerous one; of the same length, as originally designed, as the "Cressy," steaming 23 to 24 knots, armed with fourteen 6-inch guns and ten 12-pounders, and having 4-inch instead of 6-inch armour. In later vessels two 7·5-inch guns have been introduced in place of four 6-inch, and the armour has been made 6-inch, with some increase in length and displacement and decrease in speed. Personally, I was desirous from the first to provide 6-inch armour; but, for the intended service, 4-inch armour and 6-inch guns were considered sufficient.

It is particularly interesting to recollect that, when in 1888 I designed the "Blake" and "Blenheim" cruisers of 9,000 tons, they were described as "monsters," and considered to go beyond reasonable limits of size and cost. Opinions have altered greatly since that date, and large cruisers have been constructed for all navies.

Protected Cruisers.

The distinction between "belted" and protected cruisers has been explained above. After the "Orlando" class of belted cruisers was built in 1885–6, the type was not further adopted for the Royal Navy. All the swift cruisers built from my designs from 1887 to 1896 were of the "protective deck" type, culminating in the "Powerful" and "Terrible" of 1894, which were specially designed to be superior in speed and coal-endurance, as well as in offensive and defensive power, to the belted cruisers "Rossia" and "Rurik" of the Russian Navy. The "Powerful" and "Terrible" are of about the same dimensions as the "Drake" class, with maximum speeds of 22 knots and rather lighter armament, but they are wood-sheathed and coppered, so as to enable them to keep the sea for long periods without serious fouling, and the necessity for docking. Their coal-supplies are also greater than those of the "Drake." It is the fashion now to treat these protected

cruisers as if they had ceased to have serious fighting-value; because more recent armoured cruisers are superior in defence or armament. The fact remains, however, that protected British cruisers maintain their full value relatively to the belted or protected foreign cruisers they were designed to meet, most of which still remain on the Active List and are reckoned in the effective force of the fleets to which they belong.

The Admiralty decided—after full consideration of the action taken in France and elsewhere (when high-explosive shells were devised), to construct cruisers with soft steel armour of 3 inches to 4 inches in thickness—that our system of protective decks and armoured casemates was preferable, and should be continued. This decision was not lightly arrived at; it was based on numerous and thorough experiments with high-explosive shells and other forms of projectiles. Adverse critics either overlook or misunderstand these facts; alleging freely either incapacity or ignorance on the part of the Admiralty, and its professional advisers, in continuing so long to build protected cruisers. All that need be said is that the most recent experiments on the "Belleisle" have obviously confirmed the previous conclusion, viz., that unless vertical armour can be worked in sufficient thickness to give reasonable protection, it is a very questionable advantage. In the later vessels of the "County" class, as already remarked, it has been thought better to accept a reduced speed, and increased dimensions, in order to increase the thickness of armour from 4 inches to 6 inches, which is a distinct contradiction of the doctrine that thin soft armour is an efficient defence. Immediately after the production of the Krupp quality of armour, which permitted considerable areas to be adequately protected without excessive weight, the Admiralty passed to real armoured cruisers; first in the "Cressy" class and next in the "Drake" class, all of which are undoubtedly superior to foreign armoured cruisers of the same date of construction.

Protective decks still remain the only form of defence for the vitals of small swift cruisers, the construction of which is still being proceeded with in all navies.

The Royal Navy possesses over one hundred protected cruisers, nearly all built from my designs. No reasonable person can doubt that these classes of cruisers are still of considerable value for the protection of commerce, for communications, and for fleet-service. Foreign authorities at least do not treat them as obsolete or valueless in their estimates of naval force.

TORPEDO FLOTILLA.

It is unnecessary to dwell at any length on the various classes of small swift vessels which have been designed specially for the use of, or for defence against, the locomotive torpedo. Starting with boats of small size, such as have already been mentioned, torpedo-boats have grown to 160 feet in length, 180 tons in displacement, and 25 knots in speed.

Torpedo-boat destroyers date from 1892. The first demand was for speeds of 26 knots to 27 knots, in order to run down the swiftest torpedo-boats then afloat. I prepared a sketch-design for the class, fixing the character and position of the armament, the coal-endurance, the nature of the accommodation, and the chief features of the type as regards load, freeboard and draught. Upon these general conditions, private firms based their designs and specifications; fixing dimensions and guaranteeing speed, stability, and other qualities. The credit of the designs, as well as the responsibility, of course, belongs to these firms. At first we were content with 180 feet in length, 250 tons displacement, and 26 knots to 27 knots. Subsequently we reached lengths of 210 feet to 220 feet, displacements of 350 tons to 360 tons, and speeds of 30 knots to 31 knots. Now there is a reaction in favour of stronger vessels, with greater sea-keeping qualities, carrying heavier loads at less speed; and vessels of 220 feet to 230 feet in length, 550 tons displacement, and 25½ knots, are being added to the flotilla. Other changes will doubtless follow.

The destroyer has, in fact, grown in length and type practically up to the torpedo gunboats of the "Sharpshooter" class, which I designed in 1887; and which, in my opinion, were about the smallest self-supporting sea-going vessels which could accompany fleets. Now that the "Sharpshooters" are fitted with efficient engines and boilers, they are realizing speeds of 22 knots to 22½ knots. In armament the gunboats are much superior to the destroyers, which carry only a few light guns, and in their accommodation and stores they are altogether different, being capable of more independent service. It is interesting to note how the two types have come together in size while preserving their distinctive features.

Recent experiments on the "Belleisle" have tended to revive an opinion that the dangers from torpedo attack have become so great by means of improvements in speed, range, and explosive charges, that the construction of large and costly battle-ships and

cruisers should be suspended. Because under special experimental conditions the "Belleisle" was sunk by a torpedo explosion, therefore it is argued even the latest and most expensive battle-ship might be destroyed by a small torpedo-vessel. History is thus repeating itself, as it is apt to do. It appears to be forgotten that many years ago ships were similarly sunk by torpedoes, and the same arguments used. Of course it is necessary in view of improvements in torpedoes carefully to consider how the defence may be strengthened, and this is doubtless being attended to. My own conviction is, however, that these improvements in torpedoes are matched by the advances made in rapidity, range, and accuracy of gun-fire and in projectiles and "bursters." So that relatively the gun and the torpedo stand much in the same relation as before. In these and in all questions of war-ship design it is necessary to take a broad and comprehensive view, not to narrow the discussion to a single feature of offence or defence.

Auxiliary Fleet-ships.

In modern fleets there is a tendency to revert to an old practice, and to associate "tenders" with the fighting-ships, or to build ships for special purposes with moderate fighting-power.

The "Hecla," a merchant-steamer, was converted into a torpedo-boat carrier and repairing-ship about 15 years ago, and carried a light armament.

In 1887 I designed the "Vulcan" torpedo depot-ship for the Royal Navy, in all essentials repeating a design I had prepared at Elswick four years before. She is a protected cruiser of 20 knots speed and moderate armament; besides being a torpedo-boat carrier, floating factory for repairs, torpedo-practice ship and depot. She has powerful hydraulic cranes for lifting boats of 18 tons weight. The aggregate weight of the boats and cranes approaches 300 tons, and the boats are carried 27 feet above water. She has been on continuous service for twelve or thirteen years and has given complete satisfaction.

Recently a large cargo-steamer, the "Assistance," has been fitted up as a floating factory to accompany the fleet. The United States Navy had a similar ship, but much smaller, with them during the war with Spain.

Water-tank vessels have also been constructed to carry fresh water for fleets, and there is a considerable weight of opinion in favour of specially constructed fleet-colliers, ammunition-ships and

store-ships, the services of which would enable the fighting-ships to carry less weight of equipment and stores.

No doubt every saving in weight carried is of great advantage, especially in ships of high speed. Much may be done by naval authorities in keeping down weights of fittings and accessories of all kinds; and they should realize that every saving in high-speed ships is multiplied three or four times in reduction of displacement. The old idea of a warship being self-supporting and capable of long-continued sea-service has been profoundly affected by the adoption of steam-power, and the necessity for frequent re-coaling. As coals must be replenished, so may other items of equipment be supplied when required at frequent intervals if the necessary arrangements are made in fixing the constitution of a fleet.

Submarine Vessels.

The British Admiralty took no action to introduce submarine vessels into the Royal Navy until the year 1901, although many such vessels had been built in France and a few for the United States Navy. Arrangements were then made with Messrs. Vickers Maxim and Co., who had acquired the rights of building boats on the "Holland" principle, similar to those which had given good results in America, and five submarine vessels were ordered for the Royal Navy. These have been completed and are on service. Lord Selborne explained that there was no conclusion as to the "future value of these boats in naval warfare," but that experiments with the new boats would "assist the Admiralty in assessing their true value." Since that time four larger and improved vessels have been ordered, and the current Navy Estimates provide for ten more. This fact indicates that the earlier boats have given satisfaction, although no official reports are available.

In this Institution we are chiefly interested in the technical problems incidental to the design and construction of submarines. These problems have been long studied and are well understood. It has always been possible to produce vessels of the class, if naval authorities required them. In the development of details, upon which success largely depends, experience is of the highest importance. Mr. Holland has unrivalled personal experience and great mechanical skill. Consequently my advice to the Admiralty was to avail ourselves of the opportunity to secure that experience, and by concentrating orders in the hands of an eminent firm many advantages are gained while secrecy is maintained. Improvements have been and will be made under the guidance of naval officers,

who try and use the vessels, as well as by the builders; and already it would appear that we stand well as to types, compared with France, although inferior in numbers. There are, however, certain unavoidable limitations and special risks, and of the latter I have had some personal experience.

Summary of Work, 1885–1902.

Excluding destroyers my responsibility for designs and construction in the period 1885–1902, included 43 battle-ships, 26 armoured cruisers, 21 first-class protected cruisers, 48 second-class, 33 third-class, and 74 unarmoured or unprotected vessels. The total represents 245 vessels with an aggregate value of about eighty millions sterling, exclusive of armaments, ammunition and reserves, for which the naval architect is, of course, not responsible. Including these items, the first cost to the nation of the 245 ships ready for service, must be at least one hundred millions sterling.

The magnitude of our war-ship building, from 1885 to 1902, may be illustrated in another way. Parliamentary returns, which few people consult, give the expenditure on new construction, in detail, for each financial year, from 1869–70 onwards. From this record it can be seen that, from 1870 to 1885, the average annual expenditure on new ships was under $1\frac{3}{4}$ million sterling. From 1885 to 1 April, 1902 (17 years), the total expenditure on new ships was about $88\frac{1}{2}$ millions sterling, the annual average being nearly $5\frac{1}{4}$ millions. For the last seven years during which I held office, the total expenditure on new ships exceeded 50 millions; the average was £7,200,000 annually, and the maximum (1900–01) nearly 9 millions.

This large expenditure, of course, involved the extensive employment of the great private firms, while the Royal dockyards contributed no small share to new construction. For the dockyards the real measure of expenditure is the cost of labour expended on new construction: since private firms furnish the materials, machinery, armour, and other items which are combined into the ships. On this basis it is probably near the truth to say that out of the $88\frac{1}{2}$ millions spent between 1885 and 1902 the dockyards expended about one-sixth, and the balance—say, 74 millions—fell to the share of the great private establishments of steel and armour-plate makers, shipbuilders, marine and mechanical engineers, timber merchants and other industries. Out of the whole sum expended probably more than 60 millions was spent on labour.

The capital value of the Fleet has been enormously increased by recent additions, not merely by the numbers of ships built, but by the great growth in the cost of individual ships consequent upon increase in size, speed, and fighting capability. I may repeat a few figures which I have previously given on this head. Taking the combatant ships of the British Navy, their total first costs have represented about the following at the respective periods:—1813, ten millions sterling; 1860, seventeen to eighteen millions; 1868, a somewhat higher figure; 1878, about twenty-eight millions; 1887, thirty-seven millions; 1902, about one hundred millions. Guns and ammunition are not included.

The value of the French national fleet in 1870 was put at 18½ millions sterling, and in 1898 at 47¼ millions, a great increase but a slower rate of growth than that of the Royal Navy.

With this enormous increase on capital value of our fleet there come, of course, larger demands for repairs and maintenance, and for accommodation in dockyards and harbours. Ships are of greater size, and docks must be made larger, harbours deepened, and mooring-space increased in home ports. Abroad, important strategic positions and naval bases have to be furnished with docks and machinery for repairs. The Admiralty scheme embraces all these matters, and has dealt with them by special Acts of Parliament. The first, framed by Lord Spencer in 1895, contemplated an expenditure of about £9,600,000; the Act of 1903 contemplates an expenditure of £21,758,000, and the debate on the subject made it clear that much larger expenditure would be necessary. Already the Admiralty have to call on private firms to supplement the resources of the dockyards in the repair of ships; and the demands for repairs must increase as the ages of the ships on the active list grow greater. As yet the full effect of the recent changes in *matériel* has not been felt, so many new ships having been brought into service. A new dockyard is contemplated on the Firth of Forth and large extensions at Chatham; but it may be confidently assumed that more extensive provision must be made, and possibly some radical alteration in the distribution of work between the Royal dockyards and private establishments will be required.

Many ships have recently been struck off the Active List and sold out of the service to be broken up. Action of this kind is absolutely necessary, and within proper limits it involves no weakening of our real force, while it produces sensible economy in cost of upkeep. It is, however, absolutely necessary to keep in mind the fact that, under modern conditions, there is every

probability that ships after taking part in a serious naval action will be so damaged as to be unfit for service without extensive repairs; so that a "reserve of ships," even if in many respects inferior to more recent types, should always be maintained. It is not improbable that at the close of a naval campaign the command of the sea may depend in great part upon ships not reckoned in the original fighting-line, and possibly treated as obsolete in some quarters.

It will be seen that, in this task of maintaining and extending the Royal Navy, very many and varied interests are involved, and that it would have been impossible of fulfilment but for the enterprise and skill of private firms. To them the nation owes much; and it is to be feared that, in some instances, the financial results of important contracts have not been satisfactory, although, on the whole, I trust that commercial advantage has not been dissociated from public service. To the officers and men of the Royal Dockyards is due also an acknowledgment of their energetic and devoted service. To my colleagues and staff at the Admiralty I would take this opportunity of tendering publicly my heartfelt thanks for loyal and unceasing assistance, as well as for numerous suggestions of the greatest value. To the public, the head of a department is naturally the chief object of interest. He takes the praise if success is achieved, and the blame if there are failures. But behind him stands his staff of assistants, taking their full share of work and responsibility, and upon their ability and loyalty much depends. Fortunately for me, many of my staff have been fellow-students, and a still larger number have been pupils of my own. Long and intimate personal acquaintance with men is an enormous advantage under such circumstances. The Royal Corps of Naval Constructors was founded 20 years ago, largely on my initiative and on lines proposed by myself. Subsequent events have proved the great value of the organization into one corps of all trained Naval Architects in the Admiralty service; and I feel assured that in the future its reputation, already high, will increase. It is not easy to obtain such men in adequate numbers when a sudden and unprecedented demand for a larger staff arises such as occurred in 1889 and has continued. This has been a serious difficulty, involving great anxiety to me throughout. We were under-manned, and the regulations of a public department do not permit the freedom and expansion which are customary in a private establishment. It is to be hoped, however, that the lesson has been learnt. Since my retirement steps have been taken to strengthen the numbers of the constructive depart-

ment; and it is true economy to ensure that an adequate staff shall always be maintained. It may be hoped that my successor will not be subjected to the severe personal pressure which came upon myself for many years.

It is proper also to record my sense of obligation to my colleagues, the three Engineers-in-Chief of the Navy with whom I served, for their valuable help and the most cordial relations which have always been maintained. Two of them are dead, Sir James Wright and Mr. Richard Sennett, and I can therefore speak freely of their great services to the Navy. Sir John Durston is still in office, his work speaks for itself, and his responsibilities have grown with the growth of the fleet.

My long official life has been marked by close association with many distinguished public servants, both naval and civil. I have served under six Boards of Admiralty, five First Lords and six Controllers of the Navy, and have been associated with six Directors of Naval Ordnance, three Engineers-in-Chief and three Directors of Dockyards. Although it was an unpleasant necessity to tender my resignation, as my health would no longer bear the strain, there is some consolation in the thought that for so long a time one has been able to render some service to our first line of defence.

It is an unquestioned article of the national faith that the maintenance of British maritime supremacy is essential not merely to the well-being, but to the existence of the Empire. This is no new doctrine; it was well understood and was acted upon centuries ago. At times it may have been obscured, or there may have been neglect of adequate measures to ensure supremacy and a careless confidence that we could live upon the reputation of the past. No such mood now possesses the nation. The events of the last fifteen years prove that, at all costs, there is a resolve to maintain our position as the greatest naval power,—not as a menace to other nations, but as a guarantee of peace on the high seas, the free flow of commerce throughout the world, and the uninterrupted communication between the widely-scattered parts of our great Empire. The Navy, meaning the mercantile as well as the war-fleet, is the essential bond of union between the Mother Country, the Colonies and possessions beyond the seas—the common asset of all. No better routes than the ocean offers, can be found for the peaceful intercourse between us and our brethren, which is the great object of our aspirations: our established policy is to hold these ocean highways open to all nations, claiming no monopoly or exclusive rights. Our war-fleets are the guardians, our merchant-ships the messengers of peace. As was well said by the three Admirals in 1888;—"No

other nation has any such interest in the maintenance of an undoubted superiority at sea as has England, whose seaboard is her frontier. England ranks among the great powers of the world by virtue of the naval position she has acquired in the past and which has never been seriously challenged since the close of the last great war. The defeat of her Navy means to her the loss of India and her colonies and of her place among the nations." Such a disaster can never happen so long as our national spirit is maintained.

The Roman Empire was far-reaching; its rulers well understood the supreme value of good communications. In this outlying portion of the Empire, farther removed from the centre under then existing conditions than our most distant possessions are now removed from the mother-country, the great roads remain as monuments to the Imperial conception. The ocean furnishes our roads with the cheapest and most convenient transport, ready made. Shipbuilders and engineers have provided the means of locomotion and have brought the Antipodes within easy reach, while the Atlantic passage is so small an enterprise that it is no more regarded than was a journey to Inverness in the last century. We all share the wish expressed recently by the President of the Iron and Steel Institute (Mr. Carnegie), that our relations with kinsfolk in the United States should be more intimate and cordial, but we do not agree with him that it is unfortunate to have an ocean between our shores instead of prairies. It is an absolute fact in modern times, that "the seas but join the nations they divide." We need no better links of communication than those which have been created and are still being improved; only never let it be forgotten that it is the "Navy whereon, under the good providence of God, the safety, honour and welfare of this Kingdom most chiefly do depend."

Sir Frederick Bramwell, Bart., Past-President, moved—"That the best thanks of the Institution be accorded to the President for his Address, and that he be asked to permit it to be printed in the 'Proceedings' of the Institution." He was sure that all who knew Sir William White rejoiced to see him in the Presidential Chair that evening. It had been a source of the greatest grief to many that Sir William had felt himself bound to pass over the acceptance of the Presidential Chair two years ago. At that time he (Sir Frederick Bramwell) had believed it to be necessary that Sir William should take that step, but to the great alarm of his friends Sir William had desired to go much further than this; he had desired to give up altogether—to resign. But he and others

of Sir William's friends had strenuously and successfully persuaded him to defer taking such a step, with the result that everything comes to those who can wait: they had waited two years, and had Sir William at last. He thought it was most desirable, in a catholic engineering society like the Institution of Civil Engineers, that the Navy, so important to the Empire, should be represented in the person of a President of the Institution. The Institution had been within reach of it once or twice, but had always failed to have a naval architect as President; but now it had a man whom no one could desire to see replaced by any other person in his particular branch of the profession. With regard to Sir William White's ability for conducting the work of an Institution, he had tried his 'prentice hand upon the Institution of Mechanical Engineers, and the manner in which he had carried out the work there had been greatly appreciated. The business of that Institution had been conducted with precision, with decision and clearness; no time had been wasted, but nothing had been injured by too great a rush: there had been a useful economy of time. He was afraid to attempt to dilate any further upon Sir William White's fitness for the office he now occupied, and the pleasure the members had in seeing him there, because it was all so well known and accepted by everybody. To himself, an old friend, as he was proud to call himself, of Sir William, it was a source of infinite pleasure to see that the efforts made to prevent his resignation had not been in vain, and that Sir William had at last been induced to occupy the Chair. He need hardly ask the members to accord him their support during his year of office, for he was sure they would do it as a matter of love and a labour of delight.

Sir BENJAMIN BAKER, K.C.B., Past-President, remarked that the President at the opening of his Address had congratulated the Institution on having veterans like Sir Frederick Bramwell and Sir George Bruce. He found to his surprise that he himself was the third venerable Past-President present, and in that capacity it became his duty and pleasure to second the vote of thanks. Sir William had said his position was due to the generous consideration of the Council, but it was well known that the difficulty had been to overcome the inertia of the natural modesty of Sir William White. It could be easily understood that, after forty years' work—an immense work, not done always under kindly criticism but sometimes under very hostile partisan criticism—Sir William had desired a rest; he had felt himself dead beat. The Institution had allowed him time, but after he had had sufficient rest for a

thoroughbred like himself the members of the Council had begun to stir him up. Then Sir William had never been able to find a quiet corner in the Athenæum without Sir Benjamin Baker sitting on one side of him and General Stirling on the other, worrying him to accept the Presidency of the Institution; and at last he, "whispering 'I will ne'er consent,' consented." The Institution was very much the better for it, and he was certain Sir William White was also the better for it.

The resolution was carried by acclamation.

The President, in reply, said it was difficult to express what he felt at the reception given to him that evening. He was accustomed —and did not value it the less on that account—to the kindness of Sir Frederick Bramwell and Sir Benjamin Baker, but the reception the members had given him, under the trying conditions of an hour-and-a-half of rapid utterance of facts that might have been a little tedious, surprised him. He felt more than he could say the honour of occupying the Chair. At one time it had appeared as if circumstances would not permit him to take the Presidency, but those had been overcome, and he hoped to be able to do some service for the Institution and certainly was willing to do his utmost with that intent.

The President then presented the Telford, Watt, George Stephenson, James Forrest and James Prescott Joule Medals; and the other awards made by the Council in respect of Session 1902-1903 were announced.

A reception was subsequently held in the Library.

10 November, 1903.

Sir WILLIAM H. WHITE, K.C.B., D.Sc., LL.D., F.R.S., President, in the Chair.

(*Paper No. 3452.*)

"Tensile Tests of Mild Steel; and the Relation of Elongation to the Size of the Test-Bar."

By Professor WILLIAM CAWTHORNE UNWIN, B.Sc., F.R.S., M. Inst. C.E.

WITH the introduction of ingot metal, or mild steel, as a constructional material, the necessity arose for careful specification of the quality required, and for systematic testing of the material supplied. The properties of steel, either in plates or in forgings, vary a good deal, with comparatively small differences of composition or treatment in manufacture; and the engineer has to rely on tests of samples for assurance that he is obtaining material suitable for any given purpose. As experience has been gained, manufacturers produce material of very uniform and trustworthy character, and the quantity rejected for failure to pass tests is very small. But the time has not arrived, and is not likely to arrive, when, for this material, regular testing can be dispensed with. It is important, therefore, that the tests should be such as to afford definite information, and should be so conducted that the results of different tests are strictly comparable. In order to secure this, something more is required than accuracy in the testing-machine, and care and honesty in the observer who makes the tests. Circumstances which modify the results of tests can be known only by a study of the behaviour of plastic materials when strained, and the results of tests require interpretation.

For the determination of the quality of steel recourse is had to: (1) chemical analysis; (2) mechanical tests, in which the material is subjected to straining action and definite measurements are made; (3) workshop tests, such as cold and temper bend tests; and (4) for certain purposes, microscopical examination of structure. Chemical analysis is of great value to the steel-manufacturer, but

the engineer is not directly concerned with the composition of steel, but only with its mechanical properties. It is only so far as the influence of different constituents, or percentages of constituents, has been ascertained by correlated mechanical tests, that chemical analysis is of value to the engineer. Hence, mechanical tests are fundamentally the most important, and if they could be made stringent enough, it would be undesirable that the steel-maker should be hampered by specifications of chemical composition. Unfortunately, mechanical tests, as hitherto made, are not wholly satisfactory, and hence they are generally supplemented by restrictions as to chemical composition and by rough but useful workshop tests. This really makes the specification of steel cumbrous and complicated, and it certainly happens that inconsistent requirements are often specified. As to chemical analysis, it should further be pointed out that it is becoming clear that the mechanical properties of steel depend quite as much on its structure as on its composition.

Ordinary commercial tests are necessarily carried out on a rigid routine system, in which speed and reduction of cost are dominant conditions. Their object is merely to detect obviously inferior material. It is not the aim of this Paper to suggest a modification of ordinary commercial tests, but only to point out some respects in which their results may be misleading. Experience shows that, under present arrangements, engineers do obtain fairly satisfactory material, though there are cases where the tests appear to fail in indicating inferiority of quality which appears afterwards in the use of the steel.

If ever the present cumbrous system of chemical, mechanical and workshop tests is to be simplified, it would seem that the mechanical tests must be made more stringent and exact. The engineer requires to know the real relative mechanical value of different samples of material, and he certainly, in general, assumes that the test-sheets, giving tenacity and elongation, furnish this information. If it is the case that ordinary tests are so conducted that the results are not strictly comparable, they are misleading, unless the causes of this are understood, and the extent of the error. It is intended in this Paper to consider some conditions which affect the results of tensile tests, especially as regards the measurement of ductility. It is just possible that if tensile tests were so carried out that the results were strictly comparable, and stricter limits of quality were insisted on, the additional tests now required might be dispensed with. Or it may be desirable that, in addition to the ordinary tests, certain special standard tests of a more exact character should be occasionally made, as a check on ordinary tests.

In any case, in research work, especially researches on the numerous new alloys of steel which are being tried, it is extremely desirable that all results should be strictly comparable. In connection with the work of the Engineering Standards Committee on ship-material, the Author carried out tests on various qualities of steel; and he took the opportunity of arranging the scheme of tests specially to throw light on the conditions which affect the measurement of elongation. It is one object of this Paper to show how elongations can be measured either on bars of the same size or on bars of different sizes, so that they are comparable and have a definite meaning.

TENSILE TESTS OF STEEL.

The most commonly imposed tests of quality for steel to be used in construction are tensile tests, in which the ultimate strength and ultimate elongation are observed. It is generally specified that the tensile strength shall not fall below some limit, say 28 tons per square inch, or exceed some other limit, say 32 tons per square inch. That the steel should have a certain known minimum strength is clearly necessary as a datum in designing, but it is less obvious why a superior limit of strength should be imposed. Prima facie the engineer requires the strongest material he can obtain. If he is content with 28-ton steel, it is only because stronger steel is either too costly or has some other defect. It may be said that a limited variation of strength is insisted on because it is undesirable in a compound structure to have plates of different strength acting together. But as the coefficient of elasticity varies very little for very great variations of tensile strength, the reason is not convincing. It is impossible to avoid the conclusion that the maximum limit of strength is imposed as an indirect test of ductility, the strongest steels being less ductile than the weaker steels. But the direct test of ductility is the percentage of elongation, and if this could be fully trusted, only a minimum strength and a minimum percentage of elongation should be specified. As workshop bend-tests are also indirect tests of ductility, it may be inferred that this quality in steel is the most important quality for working-purposes which the engineer aims at securing. Hence it is unfortunate that, of all the measurements made in mechanical tests, the percentage of elongation, which is the most definite measure of ductility, is the one most affected by some conditions of testing not generally understood, and usually overlooked.

Ductility.—By ductility is meant the property of plastic yielding, a property which, much increased at high temperatures, permits steel to be moulded by rolling or hammering. The converse of ductility is rigidity or hardness. In tensile tests the ductility is measured by the amount of permanent or plastic elongation reckoned per unit length. For the product of strength and elongation, reckoned per cubic unit, a quantity which in similar materials is proportional to the work of deformation, the term toughness is used, and the converse of this is brittleness.

The importance of ductility is due to this, that in the operations of the workshop, and from defects of accuracy of workmanship in compound structures (riveted structures, for instance), the limit of elasticity is often exceeded locally. A ductile material will yield in such cases, and the variation of stress will be much less than it would be in a material incapable of plastic deformation. Recently, notched-bar tests, either by statical loads or by impact, have sometimes been described as tests of ductility. It appears to be overlooked that by notching a bar, its ductility in the ordinary sense is destroyed. Such a bar breaks by a progressive tear, starting from the nick, and there is no measurable deformation in the plane of fracture. Tests of this kind probably have a considerable technical value, but the interpretation of them requires further study.

Time Effect in Testing.—With the weaker metals the results of testing differ considerably, according as the rate of loading is fast or slow. In the case of steel the time effect is negligibly small, as respects both breaking stress and elongation, for such variation of rate as is likely to occur in ordinary testing. But this is only true provided no inertia-forces due to the testing-machine itself come into play. With all forms of testing-machine, and especially with some forms used in this country, inertia-forces of considerable magnitude may be introduced, if there are considerable variations in the rate of straining. The use of accumulators permits excessively rapid straining in the final stages of a test. In the German State Laboratories the rate of elongation during test is limited to 2 per cent. per minute; but in this country the rate is often 25 per cent. per minute. Inertia effects will, other things being equal, be 136 times as great in the latter case as in the former. Some apparently inexplicable anomalies in ordinary testing are, in the Author's opinion, due to unreckoned inertia-forces at the end of a test carried out more rapidly than is desirable.

Methods of Gripping the Test-Bar.—The condition to be satisfied is that the resultant of all the forces acts along the axis of the bar.

If it does not, a bending stress is added to the tension. In very careful testing the bar has shoulders or screwed ends, and these rest on spherical seatings. Even so, all bending stress is not quite eliminated, as may be seen from the difficulty of breaking cast-iron bars quite fairly. Ordinarily, some form of wedge friction-grips are used, and if these have swivelling seatings they act quite well for such a material as mild steel, when care is taken. A ductile bar should break at the axis or centre of the cross section first, and this is shown in good tests by the gaping of the fractured surfaces when placed together. The normal fracture for mild steel is cup-shaped, showing conical or pyramidal shearing surfaces. Occasionally a single oblique shear, at about 45° with the axis, is shown, and it is then doubtful if the test is quite satisfactory. A worse form of fracture which occurs with wide thin plates badly gripped is an irregular tear from one edge of the bar. When this occurs it may be inferred that the stress was not axial and the test should be rejected. It would be very useful to have a classification of forms of fracture, to be noted on test-sheets. But such schemes as have been proposed appear unnecessarily complicated.

Effect of Enlarged Ends.—When, in the reduced part of the bar, the stress passes the yield-stress, and the deformation is considerable, the stress on the enlarged ends is still below the elastic limit, and they are very slightly deformed. Hence, the deformation in the reduced part near the ends is hindered. This effect extends for some distance from the enlarged ends. In ordinary test-bars, especially short bars, the effect almost certainly extends to the part between the gauge-points, and so affects the percentage of elongation.

Yielding.—The striking phenomenon at the yield-point, when the bar takes a large extension without increase of load, has been traced by Professor Ewing to slips along parallel planes in each individual crystal. This slipping is not simultaneous all along, but generally begins at one point and progresses along the bar, as is shown by the curious shear-lines on its surface, which have been investigated by Hartmann and others. The distribution of elongation along the bar after fracture is rarely quite uniform, and this, which is commonly attributed to variations of hardness, may be due to variations in the average orientation of the crystals, rendering deformation by slips easier in some parts than in others.

Influence of the Position of Fracture on the Percentage of Elongation.—If a test-bar is initially marked out in ½-inch divisions, and these are measured after breaking the bar, the elongation in each

½-inch length can be found. If the rates of elongation in each ½-inch are plotted as ordinates, distances along the bar being abscissas, a curve of distribution of elongation, such as *a a a*, Fig. 1, Plate 1, is obtained. The rate of elongation near the fracture is very great; it diminishes towards the ends of the bar and the curve is practically symmetrical on either side of the fracture. It appears probable, from measurements on long bars, that if there were no enlarged ends the curve would have the form *b a b*, the rate of extension beyond the local contraction being uniform, or very nearly so, and equal to the general elongation. The length affected by local elongation is *e f*. Let *c c'* be a gauge-length, so taken that the fracture is at the centre. The mean elongation per cent. in *c c'* is the mean ordinate of the shaded area *c a c'*. If *d d'* is a gauge-length equal to *c c'*, but with the fracture not at the centre, the mean elongation per cent. will be less than that in *c c'*, for the mean ordinate of the curve over *c d* is greater than the mean ordinate over *c' d'*. Hence, if the elongation is measured between two initially fixed gauge-points (as is usual), the percentage of elongation will be less when fracture occurs near the gauge-points than when it occurs at the centre between them. Percentages of elongation of two bars are not strictly comparable unless fracture occurs at similar points in each. But in practice fracture occurs at various positions between the gauge-points. If elongation with fracture at the centre is taken as standard, then, when the bar does not break at the centre, there is what may be regarded as an error in the measurement of elongation, which always tells against the steel-maker. It is desirable to examine the magnitude of this error.

In all the tests recorded in this Paper, the bars were marked in ½-inch lengths before testing, and the elongations in each ½-inch length were measured after fracture. A simple instrument (Figs. 2, Plate 1) was devised for the purpose. The bar was placed parallel to an accurately divided metal scale along which travelled a slide carrying a pointer. The pointer was brought to coincide with each mark in turn, and the distance along the scale was read by a vernier. In this way readings could be taken rapidly, and there was no cumulative error such as might arise in measuring the ½-inch lengths separately. From the measurements the elongations in gauge-lengths of 2, 4, 6, 8, 10, 12, and sometimes 14 and 16 inches, were computed, and so that always the fracture was at the middle of the gauge-length. The error when the fracture is not at the middle of the gauge-length can be found from these data thus:—Let e_1 be the percentage of elongation in a

gauge-length $l + 2x$, and e_2 the elongation in a gauge-length $l - 2x$, the fracture being at the centre in both cases. Then the elongation in a gauge-length l, when the fracture is at x from the centre is $e = \frac{1}{2}(e_1 + e_2)$. The following Table gives some results. It will be seen that the percentage of elongation is not greatly affected unless the fracture is near one of the gauge-points, or, in fact, unless the gauge-point is within the part affected by local contraction.

ELONGATION PER CENT. IN 8 INCHES, WHEN THE FRACTURE IS NOT AT THE CENTRE OF THE GAUGE-LENGTH.

Number of Bar	2361	2362	2363	2364	2365	2390	2391
Fracture at centre							
$x = 0$	29·2	29·5	29·8	25·3	29·0	26·7	30·5
$x = 1$	29·1	29·5	29·7	25·3	29·0	26·6	30·5
$x = 2$	28·9	29·5	29·8	25·3	29·0	26·6	29·7
$x = 3$	28·1	29·1	29·2	24·4	28·5	26·6	28·3
Fracture at gauge-point							
$x = 4$	23·5	23·9	24·4	20·2	24·1	23·2	23·5

In these bars the gauge-points were not near the enlarged ends, but in bars where that is the case the percentage of elongation is also affected by the ends.

In Fig. 3, Plate 1, a few of the results on ordinary plate test-bars have been plotted in curves, showing the distribution of elongation along the bar. Some of these show considerable variation of elongation at different points along the bar. In certain extreme cases, besides the local contraction at fracture there is a second partially-formed contraction.

In the State laboratories in Germany it is usual to mark all bars in centimetre lengths and to compute the elongation for a gauge-length having fracture at the centre. This is laborious, and it would be practically accurate if bars were not rejected for small deficiencies of elongation when fracture occurs outside the middle half of the gauge-length.

Variation of Section between Gauge-Points.—Variation of section between gauge-points may arise in plate test-bars from sensible variation of thickness of the plate, and this is sometimes an irregular variation of thickness due to surface roughness, sometimes a regular variation along or across the test-bar due to rolling. Besides this, the milled edges are sometimes not strictly parallel. The Author generally measures three thicknesses on

each edge and three widths of the plate, and variations of section are in this way often found. In turned bars such variations can be made very small, but it is less easy to eliminate them in plate test-bars. It is not generally known how considerably such variations of section affect the results of the test. Very careful experiments on bars in which variations of section were purposely introduced have been made by Diegel.[1] The test-bars were carefully turned rods, and the parallel part was reduced a little midway between gauge-points over a length of 0·4 inch, the reduced part being connected with the parallel part by a cone 0·6 inch long on either side. The following Table gives the

EFFECT OF VARIATION OF CROSS SECTION. (DIEGEL.)

Material.	Gauge-Lengths.	Diameter between Gauge-Points.			Breaking Stress. Tons per Square Inch Reckoned on Smallest Section.	Elongation per Cent.
		Turned.	Reduced near Centre to	Reduction near Centre.		
	Inches.	Inch.	Inch.	Inch.	Tons.	Per Cent.
Martin steel . . .	8	0·8	..	0·0	26·9	30·2
			0·796	0·004	27·1	25·3
			0·792	0·008	26·9	24·1
			0·788	0·012	27·2	21·5
			0·784	0·016	27·6	20·3
Martin steel . . .	4	0·4	..	0·0	26·0	29·0
			0·396	0·004	26·3	22·9
			0·392	0·008	26·8	20·0
			0·388	0·012	26·1	18·2
			0·384	0·016	26·4	16·2
Tiegel steel . . .	8	0·8	..	0·0	30·8	29·0
			0·796	0·004	30·8	24·2
			0·792	0·008	31·1	22·2
			0·788	0·012	31·2	21·2
			0·784	0·016	31·3	19·1
Crucible steel . .	4	0·4	..	0·0	30·4	30·1
			0·396	0·004	31·0	21·9
			0·392	0·008	30·7	19·4
			0·388	0·012	31·2	17·4
			0·384	0·016	31·1	16·3
Special steel . . .	4	0·4	..	0·0	53·1	14·8
			0·396	0·004	55·1	11·3
			0·392	0·008	53·3	10·6
			0·388	0·012	54·5	8·9
			0·384	0·016	54·9	8·7

[1] "Der Einfluss von Ungleichmässigkeiten in Querschnitte des prismatischen Theiles eines Probestabes." Zeitschrift des Vereines Deutscher Ingenieure, vol. xlvii. p. 426, 1903.

results. The breaking stress reckoned on the reduced section increases a little as the reduction is greater. On the other hand, the ultimate elongation is very greatly affected, diminishing as the reduction is greater. No doubt this is due to diminution of local contraction. The effect, which is due to the same cause as that which reduces elongation near enlarged ends, is shown both in mild steel and in comparatively hard steel bars. In accurate testing great care should be taken not to use test-bars in which there is a sensible variation of cross section.

Components of the ultimate Elongation.

The total elongation of a bar in a gauge-length l is made up of two parts, one due to a general elongation, approximately uniform along the bar, and therefore proportional to l, the other due to a local stretch and contraction of section which occurs in the last stage of testing, after the maximum load has been reached. This local stretch depends on the sectional area of the bar, but not at all on the length between gauge-points. Hence, at least very approximately, the total elongation e for bars of the same material and cross section is—

$$e = a + bl \quad \ldots\ldots\ldots \quad (1)$$

where a and b are constants. The first term on the right is the local, and the second term the general elongation. The equation is applicable if l is not less than the length affected by local stretching, or so great that the elongation is sensibly affected by the enlarged ends. This equation has been given before,[1] and has been verified in many cases. The percentage of elongation is

$$e\% = 100\frac{e}{l} = 100\left(\frac{a}{l} + b\right)$$

or, if the numerical constant is included in the other constants,

$$e\% = \frac{a}{l} + b \quad \ldots\ldots\ldots \quad (2)$$

It is clear that the percentage of elongation for a bar of a given size diminishes as the gauge-length is greater. This is well known; and it is common to specify the gauge-length in which the elongation is measured. It is not generally recognized that the part of the elongation due to local contraction depends on the

[1] Unwin, "Testing of Materials," p. 70.

section of the test-bar, and that, therefore, the percentage of elongation in a given gauge-length increases as the section of the bar is greater.

To obtain strictly comparable elongations, the gauge-length and cross section must have a definite relation and must be specified. The difficulty of comparing the elongations of different test-bars would probably disappear if the general elongation, or elongation at the moment of maximum load, were taken as the measure of ductility, and this has sometimes been proposed. But there is no way hitherto known for obtaining the general elongation except by taking an autographic load-strain diagram.

Elongation of Geometrically Similar Test-Bars (Barba's Law).—Geometrically similar bars of different size deform similarly and are geometrically similar after deformation. Fig. 4, Plate 1, shows two similar test-bars, the ratio of their linear dimensions being n. If a, b, and c, d, are similarly placed points in the undeformed bar, they will be similarly placed after deformation. If $l_2 = nl_1$, the elongation in l_2 will be n times that in l_1, and the percentage of elongation will be the same in l_2 and l_1. Obviously the percentage of elongation in equal gauge-lengths l_1 and l_2 will be different.

The general law that similar test-bars deform similarly was first stated by Mr. J. Barba.[1] It follows that, for cylindrical test-bars, the percentage of elongation is constant for a given material, if the ratio of gauge-length to diameter is constant. In plate test-bars not strictly geometrically similar the percentage of elongation is practically constant, if the ratio of gauge-length to square root of cross section is constant. The form of cross section within somewhat wide limits, if the area is constant, does not appear to influence the elongation.

Mr. W. Hackney, in 1884, read a Paper before the Institution on "The Adoption of Standard Forms of Test-Pieces." The main object of that Paper was to explain the importance of Barba's law in testing. Mr. Hackney stated that "when the test-pieces are either of different diameters and equal lengths, or of different lengths and the same diameter, the percentages of ultimate stretching, when portions of the same metal bar are tested, are very different," and he indicated "the impossibility of comparing the results of tests, made by different experimenters, of the ultimate stretching of metals, in the absence of standard forms of test-pieces." But in applying Barba's law, Mr. Hackney was not

[1] "Résistance des matériaux. Épreuves de résistance à la traction. Étude sur les allongements des métaux après rupture." Mémoires de la Société des Ingénieurs Civils, 1880, part 1, p. 682.

consistent. He proposed a fixed ratio of length to diameter for cylindrical bars. But as regards plate bars he clearly did not see his way to any procedure which would secure that elongation results should be comparable.

German Rules for Tensile Tests.—In Germany, where most of the testing is done in State laboratories, the importance of Barba's law has been better recognized than elsewhere. A normal form of test-bar has been generally adopted, for both cylindrical and plate test-bars, with a gauge-length of 20 centimetres (8 inches) and a section of 3·14 square centimetres (0·487 square inch). Such bars satisfy the relation,

$$l = 11 \cdot 3 \sqrt{A} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where l is the gauge-length and A the area of section. If bars of a different section must be used, the gauge-length is modified so that (3) is still satisfied. Such bars are termed proportional bars, and may be regarded as virtually similar bars.

Law of Variation of Percentage of Elongation in Geometrically dissimilar Bars.—The law of variation of elongation with gauge-length is given in equation (2); it remains to find the variation when the cross section varies. But the percentage of general elongation is independent of the size of test-bar, and only the variation of local elongation requires to be examined, that is, the term a in equation (1). Now, if the parts of two bars of similar cross section affected by local contraction are similar after fracture, the local contraction must be proportional to the linear dimensions of the cross sections. Or, since the exact form of the cross section does not appear to much affect the elongation

$$a = c\sqrt{A}$$

Putting this in equation (1) and proceeding as above, the percentage of elongation is given by the equation

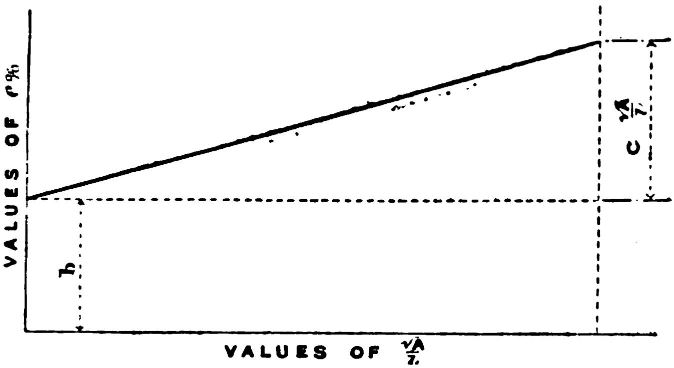
$$e\% = \frac{c\sqrt{A}}{l} + b \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where c and b are constants for a given material.[1] The first term on the right is the percentage of local, and the second term the percentage of general, elongation. The equation applies if the gauge-points are not very close to the enlarged ends, and if l is not so short that the gauge-points fall within the local contraction. So far as the Author has examined, l must not be less than from $2\sqrt{A}$ to $3\sqrt{A}$. No doubt this length depends somewhat on

[1] A method of finding c and b from a series of observations is given in Appendix III.

the quality of the material. The equation is a linear one, so that if values of $\sqrt{A}/l$ are taken as abscissas and values of $e\%$ as ordinates, the equation gives a straight line (*Fig. 5*). The equation cannot be expected to be quite exact, partly because small local variations of homogeneity modify the local contraction, and because for a similar reason the general elongation is never quite uniform along the bar. Nevertheless it will be found to express

Fig. 5.



with practical accuracy the relation of elongation to gauge-length in bars of very different proportions, and, with suitable modifications of the constants, in bars of very different quality. It should be noticed that equation (4) satisfies Barba's law that the percentage of elongation is constant in similar bars of a given material. As examples of the verification of equation (4), some of the results obtained by Mr. Barba, given in Mr. Hackney's Paper[1] will be used.

TABLE 1.—ANNEALED SOFT STEEL (CYLINDRICAL BARS).

Diameter Varied.

$$e\% = \frac{94\sqrt{A}}{l} + 21\cdot 1 = \frac{83\cdot 3d}{l} + 21\cdot 1$$

Diameter d.	Gauge-Length l.	$\frac{l}{d}$	$e\%$ Observed.	$e\%$ Calculated.	Error of Equation.
Inch.	Inches.		Per Cent.	Per Cent.	
0·8	4	5	37·5	37·8	+ 0·3
0·4	4	10	30·2	29·4	− 0·8
0·2	4	20	25·0	25·3	+ 0·3

[1] Minutes of Proceedings Inst. C.E., vol. lxxvi., p. 70.

TABLE 2.—HALF HARD STEEL (CYLINDRICAL BARS).

Diameter Varied.

$$e\,\% = \frac{66\cdot9\sqrt{A}}{l} + 14\cdot4 = \frac{59\cdot3d}{l} + 14\cdot4$$

Diameter d.	Gauge-Length l.	$\frac{l}{d}$	e % Observed.	e % Calculated.	Error of Equation.
Inch.	Inches.		Per Cent.	Per Cent.	
0·8	4	5	25·9	26·3	+ 0·4
0·4	4	10	21·0	20·3	− 0·7
0·2	4	20	17·0	17·4	+ 0·4

These Tables show that the equation is approximately true for a large variation of section (16 to 1) and constant gauge-length.

TABLE 3.—CYLINDRICAL TEST-PIECES CUT FROM A SOFT STEEL BAR.

Gauge-Length Varied.

$$e\,\% = \frac{60\cdot9\sqrt{A}}{l} + 22\cdot8 = \frac{54\,d}{l} + 22\cdot8$$

Diameter d.	Gauge-Length l.	$\frac{l}{d}$	e % Observed.	e % Calculated.	Error of Equation.
Inch.	Inches.		Per Cent.	Per Cent.	
0·688	2	2·91	42·0	41·1	− 0·6
0·688	4	5·81	32·0	32·1	+ 0·1
0·688	6	8·73	29·3	29·0	− 0·3
0·688	8	11·60	27·2	27·5	+ 0·3
0·688	10	14·49	26·6	26·5	− 0·1
0·688	12	17·39	26·0	25·9	− 0·1
0·688	14	20·33	25·1	25·5	+ 0·3
0·688	16	23·31	25·0	25·1	+ 0·1
0·688	18	26·18	24·9	24·9	0·0
0·688	20	29·07	24·8	24·7	− 0·1

This verifies the equation for bars of constant section and widely different gauge-length (10 to 1).

TABLE 4.—TEST-BARS OF STEEL PLATE.

Rectangular Sections of Different Proportions.

$$e\,\% = \frac{67\cdot6\sqrt{A}}{l} + 24\cdot1$$

Width.	Thickness.	Area.	Gauge-Length.	$\frac{l}{\sqrt{A}}$	e % Observed.	e % Calculated.	Error of Equation.
Inches.	Inch.	Sq. Inch.	Inches.		Per Cent.	Per Cent.	
0·4	0·4	0·16	4	10·0	31·0	30·9	− 0·1
0·8	0·4	0·32	4	7·0	34·0	33·7	− 0·3
1·2	0·4	0·48	4	5·8	35·0	35·8	+ 0·8
1·6	0·4	0·64	4	5·0	37·2	37·6	+ 0·4
2·0	0·4	0·80	4	4·5	39·0	39·2	+ 0·2
2·4	0·4	0·96	4	4·1	40·8	40·7	− 0·1

This verifies the equation for test-bars varying in area, and

especially for bars in which the forms of the cross sections were very different.[1]

If in testing it is inconvenient to use geometrically similar bars, the percentage of elongation in similar bars can be deduced from measurements on dissimilar bars in this way. Instead of measuring the elongation on one gauge-length only, it must be measured on two gauge-lengths on each bar. Then the constants c and b (equation 4) can be found for each bar, and the percentage of elongation for any standard form of test-bar, for instance, for the German normal bar in which $l = 11 \cdot 3 \sqrt{A}$, can be calculated. If this method were followed, percentages of elongation would be strictly comparable. Strictly, the elongations must be computed for fracture at the middle of the gauge-length, so that the plan of initially marking out half-inch lengths along the bar should be followed.

Variation of General and Local Elongation for Material of the Same Quality, with Different Proportions of Test-bars.—If average values of the constants in the elongation-formula are taken, the elongations for different proportions of bar can be calculated. This is instructive in showing the amount of misconception which may arise if elongations of bars of different proportions are compared as if they were equivalent.

The elongation assumed is:—

$$e\% = \frac{70\sqrt{A}}{l} + 18$$

which is about an average for mild steel plates not very thick.

CASE I.—TEST-BAR OF 1 SQUARE INCH SECTION AND VARYING GAUGE-LENGTH.

Gauge-Length.	Elongation.		
	General.	Local.	Total.
Inches.	Per Cent.	Per Cent.	Per Cent.
4	18	17·5	35·5
6	18	11·7	29·7
8	18	8·8	26·8
10	18	7·0	25·0
12	18	5·8	23·8
16	18	4·4	22·4
20	18	3·5	21·5

[1] The elongation formula is derived from very simple rational considerations, but it could not be accepted as trustworthy without careful comparison with the results of tests. The Author obtained it some years since, but laid it aside because he had not the necessary data to test it. Since the Paper was written

CASE II.—TEST-BARS OF THE SAME THICKNESS BUT VARYING IN WIDTH.
(Gauge-length, 8 inches.)

Thickness of Test-Bar.	Width of Test-Bar.	Area of Section.	$\frac{l}{\sqrt{A}}$	Elongation.		
				General.	Local.	Total.
Inch.	Inches.	Sq. Inches.		Per Cent.	Per Cent.	Per Cent.
½	1	0·5	11·3	18	6·2	24·2
½	1½	0·75	9·2	18	7·6	25·6
½	2	1·0	8·0	18	8·8	26·8
½	2½	1·25	7·2	18	9·8	27·8
½	3	1·50	6·5	18	10·7	28·7
½	3½	1·75	6·0	18	11·6	29·6
1	1	1·0	8·0	18	8·8	26·8
1	1½	1·5	6·5	18	10·7	28·7
1	2	2·0	5·7	18	12·4	30·4
1	2½	2·5	5·1	18	13·8	31·8
1	3	3·0	4·6	18	15·2	33·2
1	3½	3·5	4·3	18	16·4	34·4

This shows the variation of elongation with fixed gauge-length and different widths of test-bar, which has not hitherto been well understood. It is exhibited still more clearly in the following Table, in which, with a fixed gauge-length, the area is varied :—

CASE III.—AREA OF SECTION OF TEST-BAR VARIED.
(Gauge-length, 8 inches.)

Area of Section.	$\frac{l}{\sqrt{A}}$	Elongation.		
		General.	Local.	Total.
Square Inches.		Per Cent.	Per Cent.	Per Cent.
0·5	11·3	18	6·2	24·2
0·75	9·2	18	7·6	25·6
1·0	8·0	18	8·8	26·8
1·5	6·5	18	10·7	28·7
2·0	5·7	18	12·4	30·4
2·5	5·1	18	13·8	31·8
3·0	4·6	18	15·2	33·2

he has found that it is also given in Martens's "Handbuch der Materialienkunde," § 116. But Prof. Martens does not appear to have tried whether it would agree with experiment, for he says :—"The equation is self-evidently only applicable to bars of considerable length." It has also been pointed out that Mr. Barba arrived at a similar equation. "Commission des Méthodes d'Essai des Matériaux," vol. iii. p. 20, 1895.

Tests of Steel Plates supplied by Messrs. Colville and Sons, Dalzell Steel Works, Motherwell, and by the Park Gate Iron and Steel Company, Rotherham.—The following tests were made at the request of the Sub-Committee on ship material, and it is believed that the steel was ordinary steel, not specially selected. The test-bars were longer than usual, in order to examine the variation of elongation for a great range of values of $l/\sqrt{A}$. The tests were made at the Central Technical College. Ten test-bars of ship-plates and ten of boiler-plates of different thicknesses were received from Motherwell, and twenty test-bars of ship-plates and twenty of boiler-plates from Rotherham; and the chemical analyses of the steel were kindly supplied. Three bars tested across the direction of rolling broke with bright fracture and small elongation, and as these were clearly exceptional they have been excluded in discussing the results. The test-bars were supplied in pairs cut from the same plate. There are some differences in the results on the bars of a pair, due to variations of quality in neighbouring parts of a plate. In dealing with the results, the means for each pair have been used. These means fall into very consistent series, and the six sets of tests tell a clear story.

There are altogether six series of tests, each series on plates varying between $\frac{1}{4}$ inch and $1\frac{1}{4}$ inch in thickness, three on ship-plates and three on boiler-plates. The details of all these tests are given in Appendix I.

First method of Dealing with the Results.—In discussing the results for the Standards Committee it was desirable to reduce the elongations to their value for standard bars, and the Author thought it best to proceed without assuming the elongation equation. For each bar, and for each gauge-length of the bar, the percentages of elongation were plotted as ordinates, and the corresponding values of $l/\sqrt{A}$ as abscissas. Fig. 6, Plate 1, shows one set of these curves. Then for any value of $l/\sqrt{A}$, for instance, for the German standard $l/\sqrt{A} = 11 \cdot 3$, the elongation can be measured from the curve.

The Motherwell bars were all cut lengthways of the plates. The Park Gate plates were cut part lengthways and part across the plates. The elongations are greater lengthways than across the plates, and generally diminish as the thickness of the plates increases. The difference of elongation in the boiler- and ship-plates was not great, except for the thicker plates. The thicker boiler-plates are distinctly more ductile than the thicker ship-plates.

Real Relative Ductility of the Motherwell and Rotherham

Plates.—The percentage of elongation is taken as the measure of ductility, but under the restriction that it must be measured on similar test-bars. From the plotted curves the percentage of elongation for each bar tested was found for bars of 8-inch gauge-length, and of 1 square inch and 0·5 square inch area, that is, for $l/\sqrt{A} = 8$ and $l/\sqrt{A} = 11\cdot3$ respectively. It is not necessary to give these results in detail, because they will be discussed in another way presently. But the mean results are instructive, and it is desirable to give them, because they have been arrived at directly by measuring the plotted curve for each bar, and without assuming any general relation between elongation and proportions of bar.

The following Tables give the mean percentages of elongation for the three series of ship-plate tests, and the three series of boiler-plate tests. The results for each separate series are in fair agreement with the mean for the three series taken together.

SHIP-PLATES.

Thickness of Plates.	Mean Elongation in 8 Inches.	
	Bars of 0·5 Square Inch Section.	Bars of 1 Square Inch Section.
Inch.	Per Cent.	Per Cent.
$\frac{1}{4}$	22·7	25·4
$\frac{3}{8}$	26·0	29·1
$\frac{5}{8}$	24·7	26·6
$\frac{7}{8}$	22·3	24·9
$1\frac{1}{4}$	19·8	22·6
Mean of all .	23·1	25·7

BOILER-PLATES.

Thickness of Plates.	Mean Elongation in 8 Inches.	
	Bars of 0·5 Square Inch Section.	Bars of 1 Square Inch Section.
Inch.	Per Cent.	Per Cent.
$\frac{1}{4}$	22·7	26·2
$\frac{3}{8}$	26·9	29·4
$\frac{5}{8}$	25·6	28·5
$\frac{7}{8}$	24·3	27·2
$1\frac{1}{4}$	24·6	27·4
Mean of all .	24·8	27·7

In Fig. 7, Plate 1, the percentages of elongation for each thickness of plate and for each of the six series of tests, for bars of 8-inch gauge-length and of 1 square inch and ½ square inch area, are plotted. For each series of bars from ¼ inch to 1¼ inch in thickness the results are connected by a line. It will be seen that these lines have all the same general form, and that the lines for the ½-inch bars are nearly parallel to those for the 1-inch bars. The chief exceptions are the end-points of the KL curves for 1¼-inch plates. But in the case of the 1¼-inch plates, three results of tests across the direction of rolling were rejected on account of defects in the plates. Hence these points are higher than they would have been if results across the plate had been included, as for the other points of the curves.

The elongations measured for similar bars, or for a constant gauge-length and constant section, tell a clear story, and the following conclusions may be drawn:—

(*a*) The relative ductility as measured by elongation is practically the same, whether the bars are 1 square inch or ½ square inch in cross-sectional area.

(*b*) The mean percentage of elongation of 1-square-inch bars is greater by 2·6 per cent. than that of ½-square-inch bars.

(*c*) The ¼-inch plates are generally less ductile than ⅜-inch plates, probably in consequence of rolling at a lower temperature.

(*d*) There is a marked decrease of ductility with increase of thickness in the case of the ship-plates.

(*e*) There is a small decrease of ductility with increase of thickness in the case of the boiler-plates, so that the thicker boiler-plates are superior in quality to the thicker ship-plates.

Relative Elongation of Test-bars of Varying Thickness and Constant Width.—In the ordinary method of preparation of plate test-bars at steelworks, a number of plates are clamped together and shaped by a milling-cutter. All the bars must then be of the same width and, under the pressure to get testing done rapidly, objection is raised to any alteration of the milling-machine to cut bars of different widths. The American Committee, which drew up standard specifications, has proposed that all plate test-bars should be 1½ inch wide, and that is the commonest width of test-bar in this country. It will be useful to examine what are the relative elongations of test-bars of varying thickness and constant width,

and how far elongations measured on bars of constant width mask the real variations of ductility of the material.

The following Tables, deduced from the plotted curves of the Motherwell and Rotherham test-bars, give the elongations for an 8-inch gauge-length and for test-bars of 1½, 2, and 2½ inches width:—

MEAN ELONGATIONS PER CENT. IN 8 INCHES WITH DIFFERENT WIDTHS OF TEST-BAR.

Ship-Plates.

Thickness of Plates.	Elongation.			Differences of Percentage.	
	Test-Bar 1½ Inch Wide.	Test-Bar 2 Inches Wide.	Test-Bar 2½ Inches Wide.	1½-Inch and 2-Inch Bars.	2-Inch and 2½-Inch Bars.
Inch.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
¼	21·7	22·7	23·5	1·0	0·8
⅜	26·4	27·7	28·9	1·3	1·2
⅝	26·4	27·5	28·6	1·1	1·1
⅞	26·2	27·7	28·9	1·5	1·2
1¼	25·2	26·3	27·3	1·1	1·0

Boiler-Plates.

Thickness of Plates.	Elongation.			Differences of Percentage.	
	Test-Bar 1½ Inch Wide.	Test-Bar 2 Inches Wide.	Test-Bar 2½ Inches Wide.	1½-Inch and 2-Inch Bars.	2-Inch and 2½-Inch Bars.
Inch.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
¼	20·9	22·7	23·7	1·8	1·0
⅜	27·1	28·2	29·2	1·1	1·0
⅝	28·2	29·5	30·8	1·3	1·3
⅞	28·6	30·0	31·3	1·4	1·3
1¼	30·6	32·1	33·8	1·5	1·7

The differences of percentage are fairly uniform, and average 1·1 per cent. for each ½-inch width in the ship-plates, and 1·34 per cent. for each ½-inch width in the boiler-plates. The elongation is greater the wider the test-bar, up to the limit at which uniform distribution of stress fails to be secured. By comparing these Tables with those previously given for bars of constant section, the extent to which the real relative ductility is masked, if measurements are made on test-bars of constant width, is clearly shown. When the width is constant, the increase of elongation, as the plates are thicker, is considerable, and the thicker plates are apparently the most ductile.

In Fig. 8, Plate 1, the results in these Tables for 2-inch test-bars have been plotted, the percentages of elongation as ordinates and the thickness of plates as abscissas. The points for each of the six series of tests are connected by a line. It will be seen that the form of these lines is quite different from those for similar bars given in Fig. 7, and that the real decrease of ductility as the thickness of the plates increases is not shown at all, or rather, there is an apparent increase as the plates are thicker.

In the following Tables the elongation in 8 inches in bars of

COMPARISON OF ELONGATIONS IN 8 INCHES MEASURED ON BARS 2 INCHES WIDE AND ON STANDARD BARS OF ½ SQUARE INCH SECTION ($l = 11 \cdot 3 \sqrt{A}$).

—	Thickness of Plate.	Elongations. Test-Bar 0·5 Sq. In. Area.	Elongations. Test-Bar 2 Inches Wide.	Difference or Error.	Error in per Cent. of the Elongation of 0·5 Inch Bar.
	Inch.	Per Cent.	Per Cent.		Per Cent.
		Ship-Plates.			
Motherwell	¼	23·9	23·9	0·0	0·0
	⅜	28·4	30·1	1·7	6·0
	⅝	26·6	29·6	3·0	11·3
	⅞	24·7	30·4	5·7	23·1
	1¼	17·8	24·0	6·2	34·8
Park Gate, lengthways	¼	23·6	23·6	0·0	0·0
	⅜	25·6	27·0	1·4	5·5
	⅝	23·2	27·3	4·1	17·7
	⅞	20·4	24·6	4·2	20·6
	1¼	20·5	26·6	6·1	29·8
Park Gate, across	¼	20·5	20·5	0·0	0·0
	⅜	24·1	26·0	1·9	7·9
	⅝	22·4	25·7	3·3	14·7
	⅞	21·7	28·0	6·3	29·0
	1¼	21·2	28·2	7·0	33·0
		Boiler-Plates.			
Motherwell	¼	28·9	28·9	0·0	0·0
	⅜	29·2	30·7	1·5	5·1
	⅝	26·2	29·9	3·7	14·1
	⅞	25·8	31·4	5·6	21·7
	1¼	23·5	31·2	7·7	32·8
Park Gate, lengthways	¼	22·9	22·9	0·0	0·0
	⅜	25·8	27·2	1·4	5·4
	⅝	25·3	29·3	4·0	15·8
	⅞	24·7	30·2	5·5	22·3
	1¼	25·7	33·0	7·3	28·4
Park Gate, across	¼	16·2	16·2	0·0	0·0
	⅜	25·6	26·7	1·1	4·3
	⅝	25·3	29·3	4·0	15·8
	⅞	22·3	28·5	6·2	27·8
	1¼	..	..	..	..

$\frac{1}{2}$-square-inch section, and that in bars of 2 inches width is compared. The former being similar bars, the percentage is a measure of the real ductility. The difference of percentage of elongation in the two cases may be regarded as the error due to using geometrically dissimilar bars of constant width.

As these results are deduced from the plotted results on bars of different thickness, the variation of quality of the steel in different plates is taken into account.

Application of the Elongation Equation (Eq. 4) to the Motherwell and Rotherham results.—The results given above have been deduced from plotted curves so that the conclusions are not dependent on theory. But it is now to be indicated that results of this kind can be deduced more easily, and probably more accurately, by using the elongation equation—

$$e\% = \frac{c\sqrt{A}}{l} + b \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The Table on p. 191 gives the values of the constants in the equation deduced from the means of pairs of results in each of the six series of tests.

The $\frac{1}{4}$-inch plates are a little irregular, probably from rolling at a low temperature. Putting these aside, both the constants b and c decrease very regularly as the thickness of the plate increases, but more markedly for the ship-plates than for the boiler-plates. The constants are lower for plates tested crossways than for plates tested lengthways.

For a bar 1 inch square and 8 inches gauge-length the mean general elongation lengthways is 18 per cent. for ship-plates and 18·9 per cent. for boiler-plates. The mean local elongation is 8·8 per cent. for ship-plates and 9·7 per cent. for boiler-plates.

In Figs. 9 and 10, Plate 1, the equations for the mean of the Motherwell and Park Gate plates tested lengthways have been plotted, the ship-plate and boiler-plate curves being given separately.

Values of $\sqrt{A}/l$ are taken as abscissas and percentages of elongation as ordinates.

Comparison of the Elongations Calculated by Formula with the Measured Elongations.—As the elongation formula

$$e\% = \frac{c\sqrt{A}}{l} + b \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

is approximate only, it is important to examine how far it agrees

VALUES OF CONSTANTS IN ELONGATION EQUATION.

—		Thickness of Plate.	Values of *c*.	Mean Values of *c* Lengthways.	Values of *b*.	Mean Values of *b* Lengthways.
			Ship-Plates.			
		Inch.				
Motherwell . .	L.	¼	85·2	77·4	16·2	16·7
Park Gate . . .	L.		69·6		17·1	
„	A.		77·9		13·4	
Motherwell . .	L.	⅜	83·3	85·2	21·0	19·2
Park Gate . . .	L.		87·1		17·4	
„	A.		75·0		17·5	
Motherwell . .	L.	⅝	52·5	58·6	22·1	20·1
Park Gate . . .	L.		64·7		18·0	
„	A.		55·4		17·5	
Motherwell . .	L.	⅞	65·6	59·9	19·1	17·3
Park Gate . . .	L.		54·2		15·5	
„	A.		48·3		15·5	
Motherwell . .	L.	1⅛	52·0	53·3	13·6	14·7
Park Gate . . .	L.		54·5		15·7	
„	A.		54·4		17·3	
Mean of all, lengthways		..	..	66·9	..	17·6
„ „ crossways		..	..	65·6	..	16·2
			Boiler-Plates.			
Motherwell . .	L.	¼	105·4	94·5	19·7	17·7
Park Gate . . .	L.		83·6		15·6	
„	A.		59·3		11·3	
Motherwell . .	L.	⅜	86·3	81·3	21·2	20·0
Park Gate . . .	L.		76·3		18·8	
„	A.		62·0		19·9	
Motherwell . .	L.	⅝	77·4	72·6	19·2	19·4
Park Gate . . .	L.		67·9		19·5	
„	A.		69·6		19·0	
Motherwell . .	L.	⅞	74·2	70·6	19·0	18·9
Park Gate . . .	L.		67·0		18·7	
„	A.		71·5		15·8	
Motherwell . .	L.	1¼	72·3	68·5	17·1	18·6
Park Gate . . .	L.		64·7		20·1	
„	A.		19·6		12·7	
Mean of all lengthways		..	..	77·5	..	18·9
„ „ crossways .		..	..	56·4	..	15·7

in detail with the experimental results. The following Tables give the calculated and observed elongations for each of the thirty pairs of tests of the Motherwell and Rotherham plates. The calculated elongations are deduced from the values of the constants given above. Allowing for the irregularity of elongation along the bar, which certainly occurs, and for errors of measurement of the $\frac{1}{2}$-inch spaces, the agreement of the calculated and observed values is very close throughout. The difference rarely exceeds 1 per cent. of elongation, and is generally much less. It should be noted that the agreement holds good for a very wide range of gauge-lengths and areas of section, and for plates of very different ductility.

MOTHERWELL SHIP-PLATES.

Number of Test-Bar	2346–7		2348–9		2350–1		2352–3		2354–5	
Thickness of Plate.	$\frac{1}{4}$ inch		$\frac{3}{8}$ inch		$\frac{5}{8}$ inch		$\frac{7}{8}$ inch		$1\frac{1}{4}$ inch	
Gauge-Length.	Elongations, per Cent.									
	Obsv.	Calc.	Obsv.	Calc.	Obsv.	Calc.	Obsv.	Calc.	Obsv.	Calc.
Inches.										
4	30·3	30·6	36·6	36·6	35·2	34·9	37·0	37·9	26·7	27·9
6	26·0	25·8	31·5	31·4	30·9	30·7	32·0	31·6	23·5	23·2
8	23·6	23·4	28·8	28·8	28·6	28·5	28·9	28·5	21·3	20·8
10	22·0	22·0	..	..	26·9	27·2	26·6	26·6	19·6	19·3
12	20·9	21·0	..	..	26·3	26·4	25·1	25·3	17·9	18·4
14	..	..	..	..	25·8	25·8	..	..	..	..

MOTHERWELL BOILER-PLATES.

Number of Test-Bar	2356–7		2358–9		2360–1		2362–3		2364–5	
Thickness of Plate.	$\frac{1}{4}$ inch		$\frac{3}{8}$ inch		$\frac{5}{8}$ inch		$\frac{7}{8}$ inch		$1\frac{1}{4}$ inch	
Gauge-Length.	Elongations, per Cent.									
	Obsv.	Calc.	Obsv.	Calc.	Obsv.	Calc.	Obsv.	Calc.	Obsv.	Calc.
Inches.										
4	37·8	38·1	36·7	37·1	37·8	37·9	40·4	40·3	37·3	37·3
6	32·4	32·0	31·7	31·8	31·8	31·6	33·5	33·2	30·5	30·5
8	28·8	28·9	29·5	29·1	28·5	28·6	29·6	29·7	27·2	27·2
10	..	..	27·8	27·6	26·7	26·7	27·3	27·5	25·2	25·2
12	..	..	26·4	26·5	25·5	25·4	26·1	26·1	23·8	23·8
14	..	..	..	..	24·5	24·5	25·1	25·1	22·8	22·9
16	..	..	..	..	..	..	..	..	22·2	22·1

PARK GATE SHIP-PLATES, LENGTHWAYS.

No. of Test-Bar	2382–3		2378–9		2374–5		2370–1		2366–7	
Thickness of Plate	½ inch		⅜ inch		⅝ inch		⅞ inch		1¼ inch	
Gauge-length.	Elongations, per Cent.									
	Obsv.	Calc.	Obsv.	Calc.	Obsv.	Calc.	Obsv.	Calc.	Obsv.	Calc.
Inches. 4	29·6	30·3	33·9	34·1	32·8	33·5	30·4	30·9	30·6	30·9
6	25·8	25·9	28·6	28·5	28·6	28·3	25·8	25·8	26·0	25·8
8	24·1	23·7	25·9	25·7	26·2	25·8	23·3	23·2	23·4	23·3
10	22·6	22·4	24·0	24·1	24·3	24·2	21·7	21·7	21·8	21·8
12	21·3	21·5	..	..	22·9	23·2	20·7	20·6	20·7	20·8
14	..	..	..	..	..	..	19·9	19·9	19·9	20·0
16	..	..	..	..	..	..	19·2	19·3	..	..

PARK GATE SHIP-PLATES, ACROSS.

No. of Test-Bar	2384–5		2380–1		2376–7		2372–3		2368–9	
Thickness of Plate	½ inch		⅜ inch		⅝ inch		⅞ inch		1¼ inch	
Gauge-length.	Elongations, per Cent.									
	Obsv.	Calc.	Obsv.	Calc.	Obsv.	Calc.	Obsv.	Calc.	Obsv.	Calc.
Inches. 4	27·9	28·4	31·4	31·8	30·2	30·8	28·7	29·3	31·5	32·5
6	23·6	23·4	26·7	27·0	27·1	26·4	25·3	24·7	27·8	27·5
8	21·1	20·9	24·8	24·6	24·4	24·2	22·8	22·4	25·4	24·9
10	19·5	19·4	23·1	23·2	22·8	22·8	21·0	21·0	23·6	23·4
12	18·3	18·4	..	..	21·9	21·9	19·9	20·1	22·1	22·4
14	..	..	..	..	21·1	21·3	19·3	19·4	..	..

PARK GATE BOILER-PLATES, LENGTHWAYS.

No. of Test-Bar	2402-3		2398-9		2394-5		2390-1		2386-7	
Thickness of Plate	½ inch		⅜ inch		⅝ inch		⅞ inch		1⅛ inch	
Gauge-length.	Elongations, per Cent.									
	Obsv.	Calc.	Obsv.	Calc.	Obsv.	Calc.	Obsv.	Calc.	Obsv.	Calc.
Inches. 4	30·1	30·2	33·3	33·3	36·4	36·1	37·2	37·9	37·1	38·5
6	25·6	25·5	28·8	28·5	30·9	30·6	31·8	31·5	32·6	32·3
8	22·9	22·9	25·9	26·1	28·0	27·8	28·8	28·3	29·8	29·3
10	..	..	24·6	24·6	26·1	26·1	26·6	26·4	27·9	27·5
12	..	..	..	..	24·8	25·0	25·1	25·1	26·3	26·2
14	..	..	..	..	24·1	24·2	24·1	24·2	25·0	25·3
16	..	..	..	..	23·7	23·6	23·3	23·5	..	..

PARK GATE BOILER-PLATES, ACROSS.

No. of Test-Bar	2404-5		2400-1		2396-7		2392-3		2388-9	
Thickness of Plate	½ inch		⅜ inch		⅝ inch		⅞ inch		1⅛ inch	
Gauge-length.	Elongations, per Cent.									
	Obsv.	Calc.	Obsv.	Calc.	Obsv.	Calc.	Obsv.	Calc.	Obsv.	Calc.
Inches. 4	23·1	22·0	31·6	31·9	35·4	36·1	34·5	36·1	18·0	18·2
6	18·5	18·5	27·7	27·9	30·5	30·3	28·7	29·2	16·5	16·4
8	16·3	16·7	26·0	25·9	28·1	27·5	26·7	25·9	15·8	15·5
10	15·1	15·6	24·9	24·7	26·2	25·8	24·4	23·9	15·3	14·9
12	14·7	14·9	23·8	23·9	24·6	24·7	22·8	22·5	14·7	14·6
14	14·6	14·4	..	..	23·7	23·9	21·5	21·4	14·1	14·3
16	..	..	..	..	23·1	23·3	20·7	20·9	13·9	14·1
18	..	..	..	..	..	..	19·9	20·3	13·8	13·9

Tests of Steel Plates with varying Percentages of Carbon, supplied by the Park Gate Iron and Steel Works, Rotherham.—Mr. F. W. Dick, of the Park Gate Works, kindly supplied a further series of test-bars cut from plates with varying percentages of carbon. Half these bars were annealed and the other half unannealed. These were tested in the same way as the other bars, and the results are instructive as showing the way in which the elongation is affected by increase of carbon. The general results of these tests are given in Appendix II.

The following Table is a summary of the results:—

ANNEALED AND UNANNEALED TEST-BARS FROM ROTHERHAM.

Carbon.	Breaking Stress in Tons per Square Inch.			Elongation in 8 Inches, per Cent.		
	Unannealed.	Annealed.	Difference.	Unannealed.	Annealed.	Difference.
Per Cent.	Tons.	Tons.	Tons.			
0·32	33·97	30·33	3·64	20·0	22·0	2·0
0·48	38·09	33·46	4·63	16·0	20·3	4·3
0·60	47·25	39·23	8·02	13·8	17·3	3·5

Two of the unannealed bars broke anomalously, one with low strength from some defect, the other outside the gauge-points. These results are not included.

The strength increases, and the elongation diminishes, with increase of carbon, and the effect of annealing is greater as the carbon increases. Taking the differences in per cent. of the values for annealed plates:—

Carbon.	Difference of Annealed and Unannealed.	
	Strength.	Elongation.
Per Cent.	Tons per Sq. Inch.	Per Cent.
0·32	12·0	9·1
0·48	13·9	21·1
0·60	20·4	20·2

The values of the constants in the elongation equation deduced from the detailed measurements of elongation are as follows:—

VALUES OF CONSTANTS IN ELONGATION EQUATION.

Unannealed Plates.

Carbon.	Thickness of Plate.	Constant c.		Constant b.	
Per Cent.	Inch.		Means.		Means.
0·32	$\frac{1}{4}$	96·4		9·2	
	$\frac{1}{2}$	69·3	76·6	14·3	12·3
	$\frac{3}{4}$	64·0		13·5	
0·48	$\frac{1}{4}$	70·4		10·3	9·0
	$\frac{1}{2}$	67·9	69·9	8·5	
	$\frac{3}{4}$	71.5		8·1	
0·60	$\frac{1}{4}$	64·5	64·5	8·3	8·3

Annealed Plates.

Carbon.	Thickness of Plate.	Constant c.		Constant b.	
Per Cent.	Inch.		Means.		Means.
0·32	$\frac{1}{4}$	82·1		16·5	
	$\frac{1}{2}$	67·5	72·2	14·7	14·7
	$\frac{3}{4}$	67·0		12·8	
0·48	$\frac{1}{4}$	50·8		15·2	
	$\frac{1}{2}$	62·2	60·4	14·2	13·9
	$\frac{3}{4}$	68·3		12·2	
0·60	$\frac{1}{4}$	69·4		10·8	
	$\frac{1}{2}$	51·0	60·1	12·0	11·0
	$\frac{3}{4}$	59·9		10·3	

The constant c on which the local extension depends varies somewhat irregularly, on the whole decreasing as the percentage of carbon increases but not differing much on the average in the annealed and unannealed bars. The constant b, which is the percentage of general elongation, varies more regularly, decreasing as the percentage of carbon increases, and being markedly greater in the annealed than in the unannealed bars. This certainly suggests that the percentage of general extension is a better index of the quality of the material than the percentage of total extension.

Significance of the Variation of Ductility with Increase of Thickness.—In the following Table are given the percentages of elongation for all the bars in nine series of tests, arranged in order of thickness of plate, and reduced to test-bars of the same form and gauge-length. With some exceptions in the case of $\frac{1}{4}$-inch plates, the reason of which is intelligible, there is a decrease of ductility with increase of thickness, almost without exception; at any rate, the rule is so general, and for steel of various quality,

that there must be a general cause for this effect. It cannot be difference of composition, for in each series the bars were of the same steel, and it must, therefore, be due to a structural difference, possibly a difference of size of the crystalline molecules in plates of different thickness.

ELONGATION PER CENT. IN NORMAL TEST-BAR,

(8-inch gauge-length and 0·5 inch area.)

$l = 11\cdot 3 \sqrt{A}$

Thickness of Plate.	Ship-Plates.			Boiler-Plates.			Annealed Plates.		
	Motherwell L.	Park Gate L.	Park Gate A.	Motherwell L.	Park Gate L.	Park Gate A.	0·32 Carbon.	0·48 Carbon.	0·60 Carbon.
Inch.									
$\frac{1}{4}$	23·7	23·3	20·3	29·0	23·0	16·5	23·8	19·7	16·9
$\frac{3}{8}$	28·4	25·1	24·1	28·8	25·6	25·4			
$\frac{1}{2}$	..	..	..	..	..	..	20·7	19·7	16·5
$\frac{5}{8}$	26·7	23·7	22·4	26·0	25·5	25·2			
$\frac{3}{4}$	..	..	..	..	..	..	18·7	18·2	15·6
$\frac{7}{8}$	24·9	20·3	19·8	25·6	24·6	22·1			
$1\frac{1}{4}$	18·2	20·5	22·1	23·5	25·8	14·4			

A criticism may be anticipated, namely, that the differences of elongation shown are small and therefore not significant. But in the Author's opinion the ordinary methods of testing with dissimilar bars in which considerable differences of elongation are found for practically similar material—differences which, of course, are not of any significance—have obscured the fact that even small differences of elongation would be significant if testing were not so roughly and unscientifically carried on.

SHORT TEST-BARS FOR FORGINGS.

Tires and Axles.—If in the case of ordinary tests of plates the results are not strictly comparable, it is much more so in the case of tests of forgings, the size and proportions of the test-pieces varying so widely in different specifications. Test-bars of 0·25 or 0·5 square inch area, or of $\frac{1}{2}$ inch or $\frac{3}{4}$ inch or 1 inch diameter, and gauge-lengths of 2 inches, $2\frac{1}{2}$ inches or 3 inches, are specified in different cases. No relation between the elongation for the same quality of material with these different test-bars has been stated, and confusion in the interpretation of the results is nearly inevitable.

It might be expected that such short test-bars are unsuitable for the application of the elongation equation, from a doubt as to whether the gauge-points lie outside the local contraction, and inside the part affected by the enlarged ends. The point requires further investigation; but the following results seem to show that the equation applies fairly approximately to these short test-bars.

Mr. F. C. Fairholme supplied the following results of tests made for Messrs. Charles Cammell and Co., of the Cyclops Steel Works, Sheffield. One series is on axle steel and one on a harder steel for tires. The tests were in pairs, and in the following Table the averages of the pairs of tests are given. The elongations were measured between fixed gauge-points irrespective of the position of the fracture, and this probably introduces some small anomalies. Half the bars were of 0·5 square inch section and half of 0·25 square inch section. All bars lettered the same were intended to be of the same quality, but there were small variations as indicated by the strength.

The following values have been deduced from the observations for the constants in the elongation equation.

VALUES OF CONSTANTS FOR MR. FAIRHOLME'S TESTS.

Axles.

Mark	c.		b.	
A_1	42	Mean 39·2	21·5	Mean 20·6
A_2	50		21·1	
B_1	39		18·1	
B_2	42		19·3	
C_1	31		22·0	
C_2	31		21·5	

VALUES OF CONSTANTS FOR MR. FAIRHOLME'S TESTS.

Tires.

Mark	c.		b.	
A_1*	..		..	
A_2	34	Mean 27·2	15·0	Mean 13·1
B_1	21		11·8	
B_2	25		12·6	
C_1	24		14·0	
C_2	32		12·0	

* Results anomalous and therefore excluded.

Elongations calculated from these values of the constants are given in the Tables below for comparison with the observed elongations. The agreement is quite satisfactory.

TESTS OF STEEL FORGINGS BY MR. FAIRHOLME.

Mark.	Gauge-Length.	Diameter in Inches.	Breaking Stress in Tons per Square Inch.	Mean Breaking Stress.	Elongation. Observed.	Elongation. Calculated from Formula.
	Inches.	Inches.	Tons.	Tons.	Per Cent.	Per Cent.
			Axles.			
A_1	2	0·798	32·05	31·69	36·5	36·3
	4	,,	31·83		30·5	28·9
	6	,,	31·38		26·4	26·5
	8	,,	31·53		23·5	25·2
A_2	2	0·565	31·96	31·96	33·5	33·6
	4	,,	32·05		26·9	27·3
	6	,,	31·88		25·7	25·3
B_1	2	0·798	35·80	36·20	32·0	32·0
	4	,,	36·38		25·0	25·0
	6	,,	36·03		22·9	22·7
	8	,,	36·60		21·5	21·6
B_2	2	0·565	35·59	35·23	30·0	29·9
	4	,,	34·96		26·0	24·6
	6	,,	35·14		21·2	22·8
C_1	2	0·798	36·73	36·59	33·0	32·9
	4	,,	36·25		27·7	27·4
	6	,,	36·69		26·7	25·5
	8	,,	36·69		23·4	24·6
C_2	2	0·565	36·48	35·66	29·3	29·3
	4	,,	35·17		25·8	25·4
	6	,,	35·35		23·6	24·1
			Tires.			
A_2	2	0·565	49·10	48·03	23·5	23·5
	4	,,	46·25		19·5	19·2
	6	,,	48·75		17·5	17·8
B_1	2	0·798	48·16	47·77	19·5	19·4
	4	,,	48·25		16·5	15·6
	6	,,	47·56		13·7	14·3
	8	,,	47·10		13·5	13·7
B_2	2	0·565	48·28	48·44	19·0	18·8
	4	,,	48·30		15·5	15·7
	6	,,	48·74		14·5	14·7
C_1	2	0·798	52·51	52·17	22·5	22·5
	4	,,	52·42		18·0	18·2
	6	,,	51·82		17·7	16·8
	8	,,	51·91		15·5	16·1
C_2	2	0·565	54·46	52·79	20·0	20·0
	4	,,	52·31		16·0	16·0
	6	,,	51·60		14·7	14·7

The constant c, on which the local extension depends, is somewhat lower, and the constant b, on which the general elongation depends, a little higher than the values for annealed plates of about the same tenacity.[1] As noted above, both constants decrease, as the percentage of carbon is higher.

The most common size of short test-bar is either 0·25 or 0·5 square inch in area. Suppose that for axle steel the constants are taken to have the mean values $c = 39{\cdot}2$ and $b = 20{\cdot}6$, and for tire steel the values $c = 27{\cdot}2$ and $b = 13{\cdot}1$. Then the elongations for various gauge-lengths would be as follows:—

ELONGATIONS OF SHORT TEST-BARS WITH VARIOUS GAUGE-LENGTHS.

Bars 0·25 Square Inch Area.			Bars 0·5 Square Inch Area.		
Material.	Gauge-Length.	Elongation.	Material.	Gauge-Length.	Elongation.
	Inches.	Per Cent.		Inches.	Per Cent.
Axle Steel .	2	30·4	Axle Steel .	2	34·5
	2½	28·4		2½	31·7
	3	27·1		3	29·8
Tire Steel .	2	19·9	Tire Steel .	2	22·7
	2½	18·5		2½	20·8
	3	17·6		3	19·5

It will be seen that the percentages of elongation vary a good deal with these varying proportions of test-bar. It would be desirable if possible to adopt the rule that for all these short test-bars the gauge-length should be taken so that

$$\frac{l}{d} = 3{\cdot}54 \quad \text{or} \quad \frac{l}{\sqrt{A}} = 4.$$

Then the bar of 0·25 square inch area would have a gauge-length of 2 inches and the bar of 0·5 square inch area a gauge-length of 2·83 inches. Probably, however, objection would be raised to this in ordinary commercial testing. But nearly the same result would be reached and the elongations be very approximately the same for a given quality of material, if test-bars of 0·25 square inch area had a gauge-length of 2 inches and those of 0·5 square inch area a gauge-length of 3 inches. The Table above shows that the elongations for these bars are nearly the same. A bar of 0·75 square inch area and 3½ inches gauge-length would give practically the same elongation. If these proportions were

[1] See p. 195.

adhered to, a comparison of the relative ductility of different qualities of steel would be easy.

Ratio of Elongations in Short Turned Test-Bars of Various Sizes.—Test-bars of forgings, tires, and axles are usually very short turned bars with screwed or collared ends. Unfortunately, it does not seem possible to adopt a standard test-bar of fixed size, or even standard bars of similar proportions, for all such cases. If that is so, it would be very useful to establish the ratio of the percentages of elongation in bars of the proportions most commonly used. Mr. Fairholme's tests permit this to be determined with a good deal of accuracy. The following are the most usual sizes of such short test bars:—

SHORT TURNED TEST-BARS.

Diameter.	Gauge-Length.	Area.	$\frac{l}{d}$	$\frac{l}{\sqrt{A}}$	$\frac{\sqrt{A}}{l}$
Inch.	Inches.	Square Inch.			
0·5641	2	0·25	3·55	4·00	0·2500
0·7980	2	0·50	2·51	2·83	0·3536
0·7980	3	0·50	3·76	4·24	0·2357
0·9772	3	0·75	3·16	3·46	0·2887

The test-bar of 0·5 square inch area and 2-inch gauge-length will be taken as the standard in the following comparisons. The following are the percentages of elongation calculated from Mr. Fairholme's tests for bars of the sizes just stated:

ELONGATIONS PER CENT. OF SHORT TURNED TEST-BARS.

Steel.	Bar 0·5 Inch Area 2 Inches Long.	Bar 0·25 Inch Area 2 Inches Long.	Bar 0·5 Inch Area 3 Inches Long.	Bar 0·75 Inch Area 3 Inches Long.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
		Axles.		
A	36·3	32·0	31·4	33·6
A	38·8	33·6	32·9	35·6
B	31·9	27·9	27·3	29·3
B	34·1	29·8	29·2	31·4
C	33 0	29·8	29·3	31·0
C	32·5	29·3	28·8	30·5
		Tires.		
A	27·0	23·5	23·0	24·8
B	19·2	17·1	16·8	17·9
B	21·5	18·9	18·6	19·8
C	22·5	20·0	19·7	20·9
C	23·3	20·0	19·6	21·2

ELONGATIONS TAKING THAT OF BAR 0·5 INCH AREA, 2 INCHES LONG, AS 100.

Steel.	Bar 0·5 Inch Area 2 Inches Long.	Bar 0·25 Inch Area 2 Inches Long.	Bar 0·5 Inch Area 3 Inches Long.	Bar 0·75 Inch Area 3 Inches Long.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
		Axles.		
A	100	88·2	86·5	92·6
A	100	86·6	84·8	91·8
B	100	87·5	85·6	91·9
B	100	87·4	85·6	92·1
C	100	90·4	88·8	94·0
C	100	90·2	88·6	93·9
Means	100	88·4	86·6	92·7
		Tires.		
A	100	87·1	85·2	91·9
B	100	89·1	87·5	93·2
B	100	87·9	86·5	92·1
C	100	88·9	87·6	92·9
C	100	85·8	84·2	91·0
Means	100	87·7	86·2	92·2

It will be seen that the mean ratios of the elongations are very nearly the same for two very different qualities of steel. Fig. 11, Plate 1, is a plotting of the equations deduced from Mr. Fairholme's tests, and from this the elongations for any proportions of test-bar can be deduced.

QUALITY FIGURE.

The standards of quality deduced from tension tests are: (1) The breaking stress—which conventionally is the maximum load before fracture divided by the initial cross section; (2) The percentage of elongation in a given gauge-length; (3) The contraction of area at fracture expressed as a percentage of the initial area. As to contraction of area it need only be observed here that its use in specifications is diminishing. It should correspond with the percentage of local elongation of length, and it does not correspond

with the percentage of total elongation of length. Some engineers specify both elongation and contraction, but then they really require two inconsistent measures of ductility. The objections to the use of contraction of area are: first, that it seems to be a good deal affected by small local defects in the place of fracture; and secondly, that in rectangular test-bars it is difficult to measure accurately, partly from the irregularities near the fracture, partly from the strongly curved form of the fractured cross section. For certain purposes no doubt it is important to specify the limit of elasticity, or the yield-stress as well as the breaking stress.

Ordinarily, however, the breaking stress and the percentage of elongation are the quantities on which the engineer relies, as measures of the quality of a constructive material; but here a difficulty arises, as there are two quantities to be considered, and attempts have been made to obtain a single figure, termed a Quality Figure or Quality Factor, combining in due proportion the breaking stress and the elongation. Wöhler proposed the sum of the breaking stress and the percentage of contraction of area as a quality factor. Others have taken the sum of the breaking stress and percentage of elongation. Tetmajer proposed the product of the breaking stress and percentage of elongation, a number which, in material of the same kind, is proportional to the work done in breaking the bar, reckoned per cubic unit. An examination of tests of rail steel led Dormus to conclude that in Tetmajer's quality factor the percentage of elongation had too predominant an influence, and he proposed as quality factor the product of the square of the breaking stress and the percentage of elongation.

If V is the quality factor; f the breaking stress in tons per square inch; e the percentage of elongation; c the percentage of contraction of area, then the quality factors are:—

Wöhler	$V = f + c$
Modified Wöhler	$V = f + e$
Tetmajer	$V = fe$
Dormus	$V = f^2 e$

All these factors must be regarded as empirical, and none of them can be safely used except within limits. A 30-ton steel with 24 per cent. elongation is a good material, and would have the modified Wöhler quality factor 30 + 24 = 54. But a 44-ton steel with 10 per cent. elongation, which would have the same

quality factor, would be unsuitable for purposes for which the 30-ton steel would be suitable.

Of these quality factors the only one much used in this country is $V = f + e$, and if limits of strength are specified, it seems to have a use in fixing a variation of elongation suitable to different values of the strength within the specified limits. Thus steel of 28 tons strength and 26 per cent. elongation, of 30 tons strength and 24 per cent. elongation, and of 32 tons strength and 22 per cent. elongation, which have the same quality factor, are probably of equal constructive value. But if a quality factor is to be used, it must be remembered that elongations must be measured on geometrically similar test-bars. It is possible that from neglect of this condition the quality factor has appeared to be more irregular than it really is. In the following Tables care has been taken to deduce the quality factor from elongations of similar bars.

The following Table gives quality factors for all the ship- and boiler-plates of which tests have been given. A fixed gauge-length of 8 inches has been taken and the elongations found for test-bars of four sizes, viz., 0·5, 1·0, 1·5 and 2·0 square inches area.

The factors for ¼-inch plates are irregular, for reasons already discussed, and there is one thick 1¼-inch plate tested crossways which is not of good quality. Putting these aside there is striking uniformity in the quality factors. The quality factor necessarily increases for the same material with the increase of section of the test-bar (*i.e.* in the horizontal rows); but the bars of any one section (vertical rows) show no great variation. The quality factor decreases fairly regularly, as the plates are thicker in most cases, showing that the thick plates are generally not quite so good as the thinner ones, but the variation is not great. The quality factor for plates tested crossways is distinctly lower than that for plates tested lengthways, as would be expected.

An important point is how far the quality factor is affected by different percentages of carbon in the plates. The Table on p. 205 gives the quality factor for the series of plates with 0·32 to 0·60 per cent. of carbon, also calculated for test-bars of four sizes. It will be seen that the quality factor has very little variation for great differences in the percentage of carbon, or, what is the same thing, of breaking-strength. So far as these tests go, it appears to increase a little, as the percentage of carbon is greater.

QUALITY FACTOR. SHIP- AND BOILER-PLATES.

(Gauge-length, 8 inches.)

Thickness of Plates.	Breaking Stress. Tons per Square Inch.	Quality Factor when Area of Section is			
		0·5 Square Inch.	1·0 Square Inch.	1·5 Square Inch.	2·0 Square Inches.
Inch.	Tons.				
	Motherwell Ship-Plates, Lengthways.				
$\frac{1}{4}$	31·0	54·7	57·9	60·2	62·3
$\frac{3}{8}$	27·5	55·8	58·9	61·2	63·2
$\frac{5}{8}$	30·0	56·8	58·7	60·2	61·4
$\frac{7}{8}$	28·9	53·8	56·2	58·0	59·6
$1\frac{1}{4}$	29·1	47·3	49·2	50·6	51·9
	Motherwell Boiler-Plates, Lengthways.				
$\frac{1}{4}$	27·4	56·4	60·3	63·1	65·6
$\frac{3}{8}$	25·9	54·7	57·8	60·2	62·3
$\frac{5}{8}$	24·7	50·8	53·6	55·6	57·5
$\frac{7}{8}$	26·1	51·7	54·4	56·4	58·1
$1\frac{1}{4}$	26·1	49·6	52·2	54·2	55·9
	Park Gate Ship-Plates, Lengthways.				
$\frac{1}{4}$	30·1	53·4	55·9	57·8	59·5
$\frac{3}{8}$	28·1	53·2	56·4	58·8	60 8
$\frac{5}{8}$	27·7	51·4	53·8	55·6	57·1
$\frac{7}{8}$	28·5	48·8	50·8	52·3	53·6
$1\frac{1}{4}$	28·1	48·6	50·6	52·1	53·4
	Park Gate Ship-Plates, Crossways.				
$\frac{1}{4}$	29·2	49·5	52·3	54·5	56·4
$\frac{3}{8}$	27·8	51·9	54·7	56·8	58·5
$\frac{5}{8}$	27·3	49·7	51·7	53·3	54·7
$\frac{7}{8}$	28·9	48·7	50·4	51·8	53·0
$1\frac{1}{4}$	27·7	49·8	51·8	53·3	54·6
	Park Gate Boiler-Plates, Lengthways.				
$\frac{1}{4}$	30·3	53·4	56·4	58·8	60·6
$\frac{3}{8}$	27·9	53·5	56·2	58·3	60·1
$\frac{5}{8}$	27·8	53·4	55·8	57·6	59·3
$\frac{7}{8}$	27·6	52·3	54·7	56·5	58·1
$1\frac{1}{4}$	28·8	54·7	57·0	58·8	60·3
	Park Gate Boiler-Plates, Crossways.				
$\frac{1}{4}$	30·0	46·6	48·7	50·3	51·7
$\frac{3}{8}$	27·7	53·1	55·4	57·1	58·5
$\frac{5}{8}$	27·5	52·7	55·2	57·1	58·8
$\frac{7}{8}$	27·0	49·1	51·7	53·7	55·4
$1\frac{1}{4}$	28·9	43·3	44·1	44·6	45·1

QUALITY FACTOR. PLATES WITH VARYING PERCENTAGES OF CARBON.
(Gauge-length, 8 inches.)

Annealed Plates.

Carbon.	Thickness of Plate.	Breaking Stress Tons per Square Inch.	Quality Factor when Area of Section is 0·5 Sq. Inch.	1·0 Sq. Inch.	1·5 Sq. Inch.	2·0 Sq. Inches.
Per Cent.	Inch.	Tons.				
	¼	29·9	53·7	56·7	58·9	60·8
0·32	½	30·4	51·1	53·5	55·3	57·0
	¾	30·7	49·4	51·9	53·7	55·3
	¼	34·0	53·7	55·6	56·9	58·1
0·48	½	33·4	53·1	55·4	57·0	58·5
	¾	33·0	51·3	53·7	55·6	57·2
	¼	40·9	57·9	60·4	62·2	63·9
0·60	½	38·8	55·3	57·2	58·5	59·8
	¾	38·0	53·6	55·8	57·4	58·8

The quality factor has been chiefly used in this country in specifications of forgings, axles and tires. The test-bars for such cases are most commonly either 2 inches or 3 inches in gauge-length, and either 0·25 square inch or 0·5 square inch in area. The following Table gives the quality factor deduced for such cases from Mr. Fairholme's tests. The variation of the factor for different sizes of test-bar should be noted. It will be seen, however, that the 2-inch bar of 0·25 square inch area and the 3-inch bar of 0·5 square inch area have nearly the same factor.

QUALITY FACTOR. MR. FAIRHOLME'S TESTS.

Quality of Steel.	Breaking Stress. Tons per Square Inch.	Quality Factor when Form of Test-Bar is 2 Inches Long by 0·25 Square Inch Area.	2 Inches Long by 0·5 Inch Area.	3 Inches Long by 0·5 Square Inch Area.
		Axles.		
A	31·7	63·7	68·1	63·1
A	32·0	65·6	70·8	64·9
B	36·2	64·0	68·1	63·5
B	35·2	65·0	69·4	64·4
C	36·6	66·4	69·6	65·9
C	35·7	65·0	68·2	64·5
		Tires.		
A	47·2	..	..	..
A	48·0	71·5	75·0	71·0
B	47·8	64·9	67·0	64·6
B	48·4	67·2	69·9	66·9
C	52·2	72·2	74·7	71·9
C	52·8	72·8	76·1	72·4

That the quality factor increases somewhat as the percentage of carbon in the steel, or the breaking strength increases, appears from the following Table, in which all the results are averaged and arranged somewhat in the order of strength.

—	Breaking Strength.	Ratio $\frac{l}{\sqrt{A}}$	Quality Factor.
	Tons per Square Inch.		
Diegel's results (8 inches × 0·8 inch) . .	26·9	11·3	57·1
„ „ (4 „ × 0·4 „) . .	26·0	..	55·0
„ „ (8 „ × 0·8 „) . .	30·8	..	59·8
„ „ (4 „ × 0·4 „) . .	30·4	..	60·5
„ „ (4 „ × 0·4 „) . .	53·1	..	67·9
Motherwell ship-plates (⅜ inch to ⅞ inch) .	28·8	..	56·3
Park Gate „ „ „ „ „	28·1	..	51·1
Motherwell boiler-plates (⅜ inch to ⅞ inch)	25·6	..	52·4
Park Gate „ „ „ „ „	27·8	..	53·1
Park Gate, 0·32 per cent. carbon . . .	30·3	..	51·4
„ „ 0·48 „ „ . . .	33·5	..	52·7
„ „ 0·60 „ „ . . .	39·2	..	55·6
Fairholme axles	34·6	2·83	69·1
„ tires	49·9	..	72·5

It is impossible to say with certainty whether the increase of the quality factor is necessarily connected with the increase of carbon and tensile strength, or whether it is due to the stronger specimens in the Table above having been of a better quality than the weaker ones. It is conceivable at least that the tires and axles were structurally better from having had more mechanical work in rolling.

The Paper is accompanied by eleven diagrams, from which Plate 1 and the Figure in the text have been prepared.

[APPENDIXES.

APPENDIXES.

APPENDIX I.

THE following are the details of the tests made for the Standards Committee (Sub-Committee on Ship Material) on steel ship- and boiler-plates supplied by Messrs. David Colville and Sons, Dalzell Steel and Iron Works, Motherwell, N.B., and by Mr. F. W. Dick, of the Park Gate Iron and Steel Company, Rotherham.

ANALYSIS OF MOTHERWELL PLATES.

The following Table contains the analysis of the steel used for the test-bars from Motherwell, supplied to the Author by Messrs. D. Colville and Sons:—

——	Ship-Plates.			Boiler-Plates.		
	A. 1013.	Y. 1660.	D. 8002.	I. 1524.	X. 736.	A. 998.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Carbon . .	0·145	0·145	0·185	0·140	0·130	0·140
Manganese .	0·530	0·560	0·720	0·500	0·480	0·420
Silicon . .	0·010	0·008	0·008	0·010	0·009	0·010
Phosphorus .	0·062	0·053	0·053	0·050	0·042	0·057
Sulphur . .	0·032	0·032	0·030	0·022	0·020	0·032

The bars were cut lengthways of the plates.

TABLE I.—MOTHERWELL STEEL PLATES. GENERAL RESULTS.

Test No.	Mark.	Dimensions in Inches. Width.	Thickness.	Area.	Breaking Stress in Tons per Sq. In.	Mean Breaking Stress in Tons per Sq. In.	Elongation in 8 Inches per Cent.	Mean Elongation in 8 Inches per Cent.[1]
				Ship-Plates.				
2346	A. 1013	1·879	0·2355	0·4425	32·00	30·97	24·9	23·6
2347	A. 1013	1·997	0·2375	0·4743	29·94		22·3	
2348	Y. 1660	1·490	0·3787	0·5643	27·64	27·51	28·3	28·8
2349	Y. 1660	1·476	0·3780	0·5579	27·37		29·3	
2350	D. 8002	1·485	0·6410	0·9516	30·11	29·97	27·0	28·6
2351	D. 8002	1·507	0·6415	0·9667	29·82		30·2	
2352	D. 8002	1·482	0·8760	1·2978	29·20	28·88	26·3	28·9
2353	D. 8002	1·504	0·8760	1·3175	28·56		31·6	
2354	D. 8002	0·979	1·2240	1·1983	29·52	29·11	20·1	21·4
2355	D. 8002	0·990	1·2385	1·2260	28·70		22·6	
				Boiler-Plates.				
2356	I. 1524	1·994	0·2537	0·5060	26·48	27·42	27·7	28·8
2357	I. 1524	1·866	0·2490	0·4646	28·36		29·8	
2358	X. 736	1·4673	0·3745	0·5495	25·73	25·87	28·7	29·5
2359	X. 736	1·466	0·3692	0·5412	26·01		30·2	
2360	X. 736	1·497	0·6210	0·9296	24·88	24·67	27·8	28·5
2361	X. 736	1·509	0·6210	0·9371	24·45		29·2	
2362	A. 998	1·477	0·8890	1·3108	26·32	26·09	29·5	29·7
2363	A. 998	1·496	0·890	1·3319	25·85		29·8	
2364	A. 998	0·983	1·2320	1·2104	26·80	26·08	25·3	27·2
2365	A. 998	1·013	1·2570	1·2733	25·36		29·0	

[1] The elongation is measured between fixed gauge-points, irrespective of position of fracture.

TABLE II.—MOTHERWELL STEEL SHIP-PLATES.

EXTENSIONS IN EACH HALF-INCH.

No. of Bar	2346	2347	2348	2349	2350	2351	2352	2353	2354	2355
Area.	0·4425	0·4743	0·5643	0·5579	0·9516	0·9667	1·2978	1·3175	1·1983	1·2260
18	..	..	..	..	..	..	..	..	..	..
17	..	..	..	..	..	0·055	0·075	..	..	..
16	..	..	..	..	..	0·095	0·075	..	..	..
15	..	..	..	..	0·08	0·115	0·095	..	..	..
14	..	..	..	..	0·085	0·125	0·075	..	..	0·05
13	..	0·05	..	..	0·080	0·145	0·115	0·065	0·04	0·04
12	0·07	0·07	..	..	0·115	0·155	0·085	0·07	0·05	0·045
11	0·08	0·075	..	..	0·10	0·15	0·10	0·085	0·04	0·045
10	0·08	0·08	..	0·085	0·105	0·15	0·08	0·10	0·10	0·04
9	0·085	0·065	..	0·105	0·095	0·14	0·10	0·07	0·10	0·04
8	0·085	0·08	..	0·09	0·105	0·125	0·095	0·12	0·05	0·04
7	0·09	0·07	0·09	0·11	0·095	0·125	0·095	0·08	0·03	0·06
6	0·09	0·08	0·13	0·11	0·11	0·13	0·11	0·12	0·07	0·05
5	0·095	0·09	0·07	0·13	0·09	0·13	0·11	0·10	0·08	0·09
4	0·075	0·09	0·10	0·12	0·105	0·13	0·10	0·14	0·08	0·065
3	0·13	0·09	0·11	0·14	0·105	0·12	0·13	0·11	0·06	0·105
2	0·11	0·11	0·15	0·14	0·12	0·15	0·13	0·19	0·11	0·10
1	0·16	0·13	0·165	0·23	0·16	0·24	0·15	0·22	0·12	0·15
Fracture.	0·44	0·41	0·43	0·43	0·35	0·43	0·34	0·48	0·20	0·30
1	0·15	0·145	0·20	0·17	0·22	0·16	0·20	0·18	0·18	0·22
2	0·12	0·095	0·15	0·13	0·135	0·14	0·14	0·18	0·115	0·10
3	0·10	0·08	0·13	0·12	0·115	0·13	0·13	0·13	0·11	0·10
4	..	0·07	0·13	0·11	0·13	0·12	0·105	0·16	0·10	0·09
5	..	..	0·10	0·09	0·11	0·10	0·095	0·10	0·085	0·10
6	..	..	0·11	..	0·10	0·10	0·08	0·14	0·10	0·11
7	..	..	0·10	..	0·11	0·10	0·10	0·07	0·09	0·10
8	..	..	0·10	..	0·11	0·09	0·08	0·13	0·10	0·09
9	..	..	..	..	0·09	0·08	0·07	0·06	0·085	0·06
10	..	..	..	..	0·07	0·06	..	0·11	0·07	0·06
11	..	..	..	..	0·06	..	..	0·06	0·07	0·05
12	..	..	..	..	..	..	..	0·08	..	0·05

Table III.—Motherwell Steel Boiler-Plates.

Extensions in Each Half-Inch.

No. of Bar	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365
Area	0·5060	0·4646	0·5495	0·5412	0·9296	0·9371	1·3108	1·3319	1·2104	1·2733
18	..	..	..	..	..	..	0·11	0·07	0·08	0·11
17	..	..	..	..	..	0·06	0·10	0·07	0·065	0·09
16	..	..	..	..	..	0·075	0·09	0·07	0·075	0·10
15	..	..	..	..	0·045	0·11	0·085	0·08	0·075	0·11
14	..	..	..	..	0·095	0·07	0·105	0·09	0·07	0·095
13	..	..	0·09	..	0·10	0·09	0·09	0·10	0·07	0·10
12	..	..	0·09	..	0·115	0·10	0·095	0·10	0·07	0·095
11	..	..	0·09	0·09	0·105	0·09	0·095	0·12	0·08	0·09
10	0·06	..	0·09	0·11	0·115	0·09	0·08	0·09	0·08	0·09
9	0·085	..	0·105	0·11	0·110	0·08	0·09	0·10	0·08	0·09
8	0·095	0·065	0·095	0·11	0·095	0·08	0·09	0·09	0·085	0·10
7	0·10	0·09	0·115	0·13	0·08	0·085	0·09	0·09	0·08	0·09
6	0·09	0·10	0·095	0·12	0·09	0·10	0·07	0·09	0·075	0·09
5	0·115	0·11	0·11	0·13	0·09	0·09	0·11	0·09	0·07	0·09
4	0·115	0·13	0·11	0·13	0·09	0·11	0·10	0·10	0·09	0·10
3	0·12	0·13	0·13	0·14	0·11	0·115	0·12	0·12	0·10	0·10
2	0·14	0·15	0·15	0·12	0·13	0·14	0·17	0·14	0·14	0·13
1	0·21	0·16	0·26	0·16	0·18	0·18	0·45	0·27	0·20	0·20
Fracture	0·45	0·48	0·41	0·48	0·45	0·51	0·46	0·53	0·47	0·54
1	0·155	0·23	0·16	0·20	0·23	0·27	0·15	0·17	0·15	0·24
2	0·14	0·16	0·13	0·15	0·12	0·16	0·12	0·12	0·16	0·15
3	0·14	0·12	0·11	0·11	0·11	0·12	0·095	0·12	0·09	0·12
4	0·10	0·13	0·10	0·11	0·10	0·10	0·065	0·12	0·09	0·11
5	0·10	0·10	..	0·10	0·11	0·10	..	0·12	..	0·08
6	0·08	0·125	..	0·08	0·11	0·095	..	0·10	..	..
7	0·07	0·085	..	..	0·12	0·085	..	0·11	..	..
8	..	0·10	..	..	0·11	0·08	..	0·06	..	..
9	..	0·06	..	..	0·12	0·05	..	..	..	..
10	..	..	..	..	0·12	..	..	..	..	..
11	..	..	..	..	0·10	..	..	..	..	..
12	..	..	..	..	0·08	..	..	..	..	..

TABLE IV.—MOTHERWELL STEEL SHIP-PLATES.

TOTAL ELONGATION IN DIFFERENT GAUGE-LENGTHS, FRACTURE AT CENTRE OF GAUGE-LENGTH.

No. of Test-Bar.	2346	2347	2348	2349	2350	2351	2352	2353	2354	2355
Area of Section .	0·4425	0·4743	0·5643	0·5579	0·9516	0·9667	1·2978	1·3175	1·1983	1·226
Value of $\frac{l}{\sqrt{A}}$ for 8 inches gauge-length . . .	12·0	11·6	10·7	10·7	8·2	8·1	7·0	7·0	7·3	7·2
In 2 inches .	0·865	0·787	0·945	0·965	0·857	0·975	0·825	1·065	0·612	0·770
„ 4 „ . .	1·285	1·139	1·450	1·475	1·322	1·495	1·322	1·640	0·985	1·152
„ 6 „ . .	1·640	1·479	1·855	1·920	1·745	1·965	1·725	2·120	1·325	1·499
„ 8 „ . .	1·995	1·779	2·265	2·340	2·162	2·412	2·102	2·525	1·605	1·804
„ 10 „ . .	2·330	2·069	..	2·725	2·541	2·844	2·439	2·885	1·905	2·019
„ 12 „ . .	2·640	2·369	..	..	2·903	3·404	2·804	3·210	2·105	2·211
„ 14 „ . .	..	..	..	..	3·263	3·974	3·194	..	..	..
„ 16 „ . .	..	..	..	..	..	4·424	..	..	..	..

TABLE V.—MOTHERWELL STEEL BOILER-PLATES.

TOTAL ELONGATION IN DIFFERENT GAUGE-LENGTHS. FRACTURE AT CENTRE OF GAUGE-LENGTH.

No. of Test-Bar.	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365
Area of Section.	0·5060	0·4646	0·5495	0·5412	0·9296	0·9371	1·3108	1·3319	1·2104	1·2733
Value of $\frac{l}{\sqrt{A}}$ for 8 inches gauge-length . .	11·3	11·7	10·8	10·9	8 3	8·3	7 0	6·9	7·3	7·1
In 2 inches. .	0·955	1 025	0·970	0·975	0·985	1·110	1·205	1·100	0·970	1·120
„ 4 „ . .	1·462	1·560	1·455	1·480	1·425	1·600	1·647	1·580	1·400	1·585
„ 6 „ . .	1·869	2·012	1·875	1·930	1·820	1·992	2·020	1·995	1·705	1·950
„ 8 „ . .	2·219	2·381	2 295	2 420	2·222	2·339	2·360	2·380	2·025	2·320
„ 10 „ . .	2·544	..	2·690	2·860	2 666	2·669	2·710	2·760	2·350	2·690
„ 12 „ . .	..	..	3 050	3·280	3·080	3 039	3·075	3 190	2·660	3·055
„ 14 „ . .	..	..	..	..	3·472	3·389	3·455	3 580	2·940	3 445
„ 16 „ . .	..	..	..	..	..	3·754	3·820	3·900	3·235	3·860

TABLE VI.—MOTHERWELL STEEL SHIP-PLATES.

PER CENT. OF ELONGATION IN DIFFERENT GAUGE-LENGTHS.
FRACTURE AT MIDDLE OF GAUGE-LENGTH.

No. of Test-Bar	2346	2347	2348	2349	2350	2351	2352	2353	2354	2355
Inches. 2	43·3	39·4	47·3	48·3	42·9	48·7	41·3	53·3	30·6	38·5
4	32·1	28·5	36·3	36·9	33·1	37·4	33·1	41·0	24·6	28·8
6	27·3	24·7	30·9	32·0	29·1	32·7	28·7	35·3	22·1	24·9
8	24·9	22·3	28·3	29·3	27·0	30·2	26·2	31·6	20·1	22·6
10	23·3	20·7	..	27·3	25·4	28·4	24·4	28·8	19·1	20·2
12	22·0	19·7	..	..	24·2	28·3	23·4	26·7	17·5	18·4
14	..	..	..	..	23·3	28·3	22·8	..	..	..
16	..	..	..	..	..	27·7	..	..	..	..

TABLE VII.—MOTHERWELL STEEL BOILER-PLATES.

PER CENT. OF ELONGATION IN DIFFERENT GAUGE-LENGTHS.
FRACTURE AT MIDDLE OF GAUGE-LENGTH.

No. of Test-Bar	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365
Inches. 2	47·8	51·3	48·5	48·8	49·3	55·5	60·3	55·0	48·5	56·0
4	36·6	39·0	36·4	37·0	35·6	40·0	41·2	39·5	35·0	39·6
6	31·1	33·5	31·3	32·1	30·3	35·2	33·7	33·3	28·3	32·5
8	27·7	29·8	28·7	30·2	27·8	29·2	29·5	29·8	25·3	29·0
10	25·4	..	26·9	28·6	26·7	26·7	27·1	27·6	23·5	26·9
12	..	..	25·4	27·3	25·7	25·3	25·6	26·6	22·1	25·5
14	..	..	..	..	24·8	24·2	24·7	25·6	21·0	24·6
16	..	..	..	..	..	23·5	23·9	24·4	20·0	24·1

Analysis of Rotherham Steel Ship-Plates.

The Park Gate Company supplied the following information. The Plates were all from one basic charge of ordinary bridge or ship quality, and of the following composition:—

	Per Cent.
Carbon	0·21
Silicon	0·009
Sulphur	0·06
Phosphorus	0·067
Manganese	0·45

Test-bars marked L cut lengthways of the plate, those marked A cut across the plate.

Table VIII.—Rotherham Steel Ship-Plates.

General Results.

Test No.	Mark.	Dimensions in Inches.			Breaking Stress in Tons per Sq. Inch.	Mean Breaking Stress.		Elongation in 8 Inches per Cent.	Mean Elongation in 8 in. per Cent.	
		Width.	Thickness.	Area.		Lengthways.	Across.		Lengthways.	Across.
2366	S.L.	1·007	1·234	1·2426	28·06	28·07		21·6	23·4	
2367	S.L.	1·004	1·238	1·2423	28·08			25·2		
2368	S.A.	1·005	1·250	1·2562	27·47	..	27·67	26·0	..	25·5
2369	S.A.	1·006	1·255	1·2625	27·87			24·9		
2370	S.L.	1·476	0·871	1·2852	28·18	28·51		22·8	23·3	
2371	S.L.	1·484	0·874	1·2950	28·85			23·7		
2372	S.A.	1·477	0·878	1·2961	(28·75)	..	28·89	(19·2)	..	26·4
2373	S.A.	1·498	0·880	1·3182	28·89			26·4		
2374	S.L.	1·482	0·620	0·9185	27·58	27·68		27·8	26·2	
2375	S.L.	1·480	0·621	0·9191	27·67			24·5		
2376	S.A.	1·480	0·623	0·9213	27·49	..	27·31	24·3	..	24·4
2377	S.A.	1·499	0·621	0·9310	27·13			24·5		
2378	S.L.	1·484	0·398	0·5904	28·49	28·07		25·1	25·9	
2379	S.L.	1·495	0·392	0·5860	27·65					
2380	S.A.	1·482	0·390	0·5777	27·84	..	27·77	25·7	..	24·8
2381	S.A.	1·494	0·390	0·5827	27·70			23·9		
2382	S.L.	1·975	0·280	0·5530	30·22	30·08		21·8	24·1	
2383	S.L.	1·991	0·298	0·5933	29·93			26·3		
2384	S.A.	1·986	0·294	0·5839	28·40	..	29·22	21·5	..	21·1
2385	S.A.	1·998	0·298	0·5954	30·04			20·6		

This Table has the elongations in a fixed gauge-length of 8 inches irrespective of the cross section of the test-bar.

Bar No. 2372 broke with very little local contraction and an exceptional fracture, part bright and coarsely crystalline and part of finer grain. The results on this bar are not included in the averages.

TABLE IX.—ROTHERHAM STEEL SHIP-PLATES.

EXTENSIONS IN EACH HALF-INCH.

Test No.	2366	2367	2368	2369	2370	2371	2372	2373	2374	2375
Area Sq. Inch	1·2426	1·2423	1·2562	1·2625	1·2852	1·295	1·2961	1·3182	0·9185	0·9191
20	..	..	..	..	0·07	..	..	..	..	..
19	..	..	..	..	0·06	0·06	..	..	..	..
18	..	..	..	..	0·07	0·06	..	..	..	..
17	..	..	..	..	0·07	0·075	..	..	..	..
16	0·07	..	..	..	0·08	0·06	..	0·07	..	..
15	0·08	..	..	0·07	0·08	0·06	..	0·08	..	..
14	0·07	..	0·035	0·07	0·08	0·065	..	0·07	..	..
13	0·075	..	0·085	0·08	0·095	0·06	..	0·07	..	0·08
12	0·065	0·08	0·065	0·06	0·085	0·07	..	0·08	0·06	0·07
11	0·07	0·09	0·075	0·07	0·095	0·07	..	0·07	0·06	0·08
10	0·075	0·10	0·07	0·08	0·085	0·07	..	0·06	0·11	0·08
9	0·08	0·085	0·075	0·09	0·085	0·07	..	0·05	0·08	0·09
8	0·09	0·095	0·085	0·10	0·09	0·08	..	0·065	0·105	0·09
7	0·075	0·08	0·085	0·11	0·075	0·08	..	0·075	0·085	0·09
6	0·09	0·09	0·095	0·13	0·10	0·08	..	0·08	0·105	0·09
5	0·07	0·095	0·10	0·12	0·08	0·09	..	0·11	0·10	0·09
4	0·09	0·095	0·11	0·12	0·105	0·10	0·085	0·12	0·10	0·09
3	0·09	0·11	0·11	0·12	0·105	0·10	0·075	0·12	0·125	0·12
2	0·14	0·11	0·15	0·12	0·125	0·14	0·07	0·16	0·135	0·12
1	0·225	0·16	0·26	0·15	0·19	0·21	0·10	0·24	0·155	0·20
Fracture	0·26	0·29	0·30	0·35	0·30	0·36	0·18	0·32	0·38	0·30
1	0·15	0·28	0·16	0·16	0·15	0·16	0·17	0·17	0·24	0·14
2	0·10	0·15	0·12	0·11	0·11	0·11	0·135	0·13	0·15	0·105
3	0·095	0·12	0·105	0·09	0·10	0·08	0·115	0·11	0·135	0·105
4	0·09	0·10	0·12	0·08	0·09	0·09	0·09	0·11	0·12	0·115
5	0·06	0·095	0·105	0·08	0·07	0·07	0·09	0·10	0·095	0·11
6	0·075	0·085	0·09	0·08	0·07	0·09	0·06	0·10	0·10	0·105
7	0·05	0·09	0·08	0·08	0·065	0·07	0·08	0·09	0·10	0·10
8	0·055	0·075	0·085	0·08	..	0·05	0·06	0·09	0·10	0·08
9	0·06	0·07	0·075	0·08	..	..	0·065	0·09	0·08	0·05
10	0·07	0·075	0·08	0·07	..	..	0·07	0·07	0·105	0·07
11	..	0·08	0·08	0·06	..	..	0·075	0·04	0·085	0·06
12	..	0·08	0·10	..	..	..	0·09	..	0·10	0·07
13	..	0·09	..	..	..	..	0·07	..	0·10	0·07
14	..	0·08	..	..	..	..	0·09	..	0·08	..
15	..	0·06	..	..	..	..	0·08	..	..	..
16	..	..	..	..	..	..	0·09	..	..	..
17	..	..	..	..	..	..	0·10	..	..	..
18	..	..	..	..	..	..	0·09	..	..	..
19	..	..	..	..	..	..	0·085	..	..	..
20	..	..	..	..	..	..	0·075	..	..	..
21	..	..	..	..	..	..	0·085	..	..	..
22	..	..	..	..	..	..	0·055	..	..	..

TABLE IX.—ROTHERHAM STEEL SHIP-PLATES.—*continued.*

EXTENSIONS IN EACH HALF-INCH.

Test No.	2376	2377	2378	2379	2380	2381	2382	2383	2384	2385
Area Sq. Inch	0·9213	0·931	0·5904	0·586	0·5777	0·5827	0·553	0·5933	0·5839	0·5954
20	..	..	..	..	..	..	..	..	..	..
19	0·04	..	..	..	..	..	..	..	...	..
18	0·00	..	..	..	..	..	..	..	..	..
17	0·07	..	..	..	..	..	..	..	..	..
16	0·065	..	..	..	..	..	..	..	..	..
15	0·095	..	..	..	..	..	..	..	..	0·07
14	0·09	0·07	..	..	..	..	..	..	..	0·06
13	0·08	0·08	..	..	..	..	..	0·05	0·06	0·07
12	0·09	0·09	0·065	..	..	..	0·07	0·06	0·05	0·07
11	0·09	0·08	0·065	0·09	..	..	0·08	0·07	0·06	0·06
10	0·09	0·08	0·085	0·09	..	0·07	0·085	0·07	0·06	0·07
9	0·09	0·07	0·065	0·09	..	0·085	0·08	0·09	0·06	0·07
8	0·07	0·08	0·08	0·10	0·07	0·075	0·09	0·09	0·07	0·06
7	0·09	0·08	0·09	0·09	0·09	0·08	0·085	0·105	0·07	0·06
6	0·09	0·08	0·09	0·09	0·09	0·07	0·11	0·11	0·08	0·07
5	0·09	0·095	0·095	0·09	0·12	0·09	0·085	0·11	0·08	0·07
4	0·11	0·10	0·095	0·09	0·11	0·08	0·085	0·105	0·09	0·08
3	0·11	0·095	0·105	0·12	0·14	0·10	0·09	0·11	0·09	0·09
2	0·18	0·11	0·115	0·13	0·20	0·11	0·10	0·12	0·10	0·105
1	0·16	0·17	0·15	0·23	0·23	0·15	0·15	0·15	0·17	0·155
Fracture	0·26	0·32	0·40	0·40	0·24	0·34	0·37	0·42	0·38	0·38
1	0·16	0·20	0·185	0·15	0·12	0·22	0·13	0·18	0·12	0·13
2	0·12	0·12	0·125	0·14	0·11	0·13	0·09	0·12	0·09	0·08
3	0·13	0·10	0·13	0·14	0·11	0·11	0·09	0·09	0·09	..
4	0·18	0·12	0·10	0·10	0·11	0·10	0·08	0·07	0·08	..
5	0·12	0·14	0·09	0·09	0·11	0·095	0·065	..	0·06	..
6	0·095	0·10	0·07	0·08	0·10	0·075	0·05	..	..	..
7	0·08	0·09	..	..	0·09	0·09	..	..	..	..
8	..	0·08	..	..	0·10	..	..	..	..	..
9	..	0·08	..	..	0·08	..	..	..	..	..
10	..	0·08	..	..	0·08	..	..	..	..	..
11	..	0·09	..	..	..	..	..	..	..	..
12	..	0·10	..	..	..	..	...	..	..	..
13	..	0·07	..	..	..	..	..	..	..	..
14	..	..	..	..	..	..	..	..	..	..
15	..	..	..	..	..	..	..	..	..	..
16	..	..	..	..	..	..	..	..	..	..
17	..	..	..	..	..	..	..	..	..	..
18	..	..	..	..	..	..	..	..	..	..
19	..	..	..	..	..	..	..	..	..	..
20	..	..	..	..	..	..	..	..	..	..
21	..	..	..	..	..	..	..	..	..	..
22	..	..	..	..	..	..	..	..	..	..

TABLE X.—ROTHERHAM STEEL SHIP-PLATES.

TOTAL ELONGATION IN DIFFERENT GAUGE-LENGTHS. FRACTURE AT CENTRE OF GAUGE-LENGTH.

No. of Test-Bar.	2366	2367	2370	2371	2374	2375	2378	2379	2382	2383
Area of Section.	1·2426	1·2423	1·2852	1·2950	0·9185	0·9191	0·5904	0·5860	0·5530	0·5933
Value of $\frac{l}{\sqrt{A}}$ for 8 inches gauge-length . . .	7·2	7·2	7·1	7·0	8·3	8·3	10·4	10·4	10·8	10·4
					Cut Lengthways of Plate.					
In 2 inches . .	0·755	0·840	0·757	0·855	0·917	0·752	0·745	0·915	0·740	0·870
„ 4 „ . .	1·150	1 297	1·176	1·255	1·430	1·191	1·307	1·405	1·092	1·277
„ 6 „ . .	1·452	1·671	1·508	1·595	1·837	1·590	1·669	1·765	1·405	1·694
„ 8 „ . .	1·731	2·013	1·823	1·895	2·226	1·962	2·009	2·130	1·745	2·104
„ 10 „ . .	2 015	2·340	2·168	2·170	2·595	2·272	2·304	2·500	2·080	2·444
„ 12 „ . .	2·292	2·677	2·528	2·450	2·942	2·557	2·584	..	2·395	2·714
„ 14 „ . .	2·577	3·017	2·883	2·705	..	..	..	..	..	..
„ 16 „ . .	2·877	..	3·203	2·950	..	..	..	..	..	..

TABLE X.—*continued.*

No. of Test-Bar.	2368	2369	2372	2373	2376	2377	2380	2381	2384	2385
Area of Section.	1·2562	1·2625	1·2961	1·3182	0·9213	0·9310	0·5777	0·5827	0·5839	0·5954
Value of $\frac{l}{\sqrt{A}}$ for 8 inches gauge-length . . .	7·1	7·1	7·0	7·0	8·3	8·3	10·5	10·5	10·5	10·4
Cut Across Width of Plate.										
In 2 inches. .	0·855	0·775	0·552	0·875	0·705	0·805	0·855	0·710	0·765	0·757
„ 4 „ . .	1·320	1·200	0·931	1·365	1·190	1·225	1·260	1·250	1·125	1·109
„ 6 „ . .	1·735	1·605	1·258	1·780	1·612	1·640	1·695	1·597	1·430	1·400
„ 8 „ . .	2·080	1·990	1·538	2·112	1·944	1·960	2·055	1·914	1·720	1·650
„ 10 „ . .	2·390	2·325	1·798	2·394	2·284	2·270	2·380	2·229	1·970	1·920
„ 12 „ . .	2·702	2·590	2·108	2·679	2·644	2·615	..	..	2·200	2·180
„ 14 „ . .	..	2·880	2·428	2·969	2·984	2·930	..	..	..	2·450
„ 16 „ . .	..	..	2·768	..	3·329	..	..	..	..	..

TABLE XI.—ROTHERHAM STEEL SHIP-PLATES.

PER CENT. OF ELONGATION IN DIFFERENT GAUGE-LENGTHS.

FRACTURE IN MIDDLE OF GAUGE-LENGTH.

No. of Test-Bar.	2366	2367	2370	2371	2374	2375	2378	2379	2382	2383
Cut Lengthways of the Plate.										
In 2 inches . .	27·7	42·0	37·9	42·8	45·9	37·6	37·3	45·8	37·0	43·5
„ 4 „ . .	28·8	32·4	29·4	31·4	35·8	29·8	32·7	35·1	27·3	31·9
„ 6 „ . .	24·2	27·8	25·1	26·6	30·6	26·5	27·8	29·4	23·4	28·2
„ 8 „ . .	21·6	25·2	22·8	23·7	27·8	24·5	25·1	26·6	21·8	26·3
„ 10 „ . .	20·2	23·4	21·7	21·7	26·0	22·7	23·0	25·0	20·8	24·4
„ 12 „ . .	19·1	22·3	21·1	20·4	24·5	21·3	21·5	..	19·9	22·6
„ 14 „ . .	18·4	21·5	20·6	19·8	..	..	..	..	..	..
„ 16 „ . .	18·0	..	20·0	18·5	..	..	..	..	..	..

TABLE XI. (*continued*).—ROTHERHAM STEEL SHIP-PLATES.

PER CENT. OF ELONGATION IN DIFFERENT GAUGE-LENGTHS.

FRACTURE IN MIDDLE OF GAUGE-LENGTH.

No. of Test-Bar.	2368	2369	2372	2373	2376	2377	2380	2381	2384	2385
Cut Across Width of Plate.										
In 2 inches . .	42·8	38·8	27·6	43·8	35·3	40·3	42·8	35·5	38·3	37·9
„ 4 „ . .	33·0	30·0	23·3	34·1	29·8	30·6	31·5	31·3	28·1	27·7
„ 6 „ . .	28·9	26·8	21·0	29·7	26·9	27·3	28·3	26·6	23·8	23·3
„ 8 „ . .	26·0	24·9	19·2	26·4	24·3	24·5	25·7	23·9	21·5	20·6
„ 10 „ . .	23·9	23·3	18·0	23·9	22·8	22·7	23·8	22·3	19·7	19·2
„ 12 „ . .	22·5	21·6	17·6	22·3	22·0	21·8	..	..	18·3	18·2
„ 14 „ . .	..	20·6	17·3	21·2	21·3	20·9	..	..	..	17·5
„ 16 „ . .	..	..	17·3	..	20·8	..	..	..	..	..

Analysis of Rotherham Steel Boiler-Plates.

The Park Gate Company supplied the following information. The plates from which the test-bars were cut were all from the same charge of acid steel of boiler quality and of the following composition:—

	Per Cent.
Carbon	0·19
Silicon	0·018
Sulphur	0·054
Phosphorus	0·048
Manganese	0·55

The pieces cut lengthways of the plate are marked L, those cut across the plate are marked A.

Table XII.—Rotherham Steel Boiler-Plates.

General Results.

Test No.	Mark.	Dimensions in Inches.			Breaking Stress in Tons per Sq. Inch.	Mean Breaking Stress.		Elongation in 8 Inches, per Cent.	Mean Elongation, per Cent.	
		Width.	Thickness.	Area.		Lengthways.	Across.		Lengthways.	Across.
2386	B.L.	1·004	1·288	1·2931	28·74	28·80		29·8	29·9	
2387	B.L.	1·009	1·286	1·2976	28·85			29·9		
2388	B.A.	0·996	1·233	1·2779	28·80	..	28·91	17·8	..	
2389	B.A.	0·999	1·278	1·2767	29·02			13·8		
2390	B.L.	1·497	0·879	1·3159	27·95	27·63		26·9	28·7	
2391	B.L.	1·496	0·887	1·3270	27·30			30·5		
2392	B.A.	1·497	0·891	1·3368	28·34	..	26·99	26·5	..	27·4
2393	B.A.	1·491	0·831	1·2390	25·64			28·3		
2394	B.L.	1·490	0·626	0·9327	27·54	27·80		25·9	28·0	
2395	B.L.	1·494	0·653	0·9756	28·06			30·1		
2396	B.A.	1·487	0·639	0·9502	27·25	..	27·54	27·6	..	28·1
2397	B.A.	1·489	0·659	0·9812	27·83			28·6		
2398	B.L.	1·495	0·390	0·5830	27·98	27·94		27·6	26·0	
2399	B.L.	1·491	0·390	0·5815	27·90			24·4		
2400	B.A.	1·496	0·406	0·6074	27·76	..	27·67	27·8	..	26·0
2401	B.A.	1·495	0·391	0·5845	27·59			24·2		
2402	B.L.	1·972	0·251	0·4948	30·76	30·31		21·3	23·8	
2403	B.L.	1·963	0·249	0·4889	29·85			24·4		
2404	B.A.	1·962	0·267	0·5237	30·18	..	30·02	16·9	..	16·3
2405	B.A.	1·985	0·264	0·5239	29·87			15·7		

Bars 2388 and 2389 broke with little local contraction and coarse crystalline fracture.

TABLE XIII.—ROTHERHAM STEEL BOILER-PLATES.

EXTENSIONS IN EACH HALF-INCH.

Test No.	2386	2387	2388	2389	2390	2391	2392	2393	2394	2395
Area	1·2931	1·2976	1·2779	1·2767	1·3159	1·3270	1·3368	1·2390	0·9327	0·9756
18	..	..	0·08	0·06	0·08	0·07	0·06	0·08	0·105	0·07
17	..	..	0·08	0·05	0·08	0·07	0·06	0·065	0·11	0·11
16	..	..	0·075	0·06	0·10	0·06	0·07	0·08	0·115	0·10
15	..	..	0·06	0·06	0·11	0·07	0·08	0·07	0·115	0·09
14	0·06	0·08	0·06	0·06	0·11	0·08	0·07	0·075	0·105	0·10
13	0·08	0·105	0·06	0·045	0·10	0·075	0·06	0·08	0·095	0·10
12	0·095	0·105	0·05	0·05	0·10	0·085	0·07	0·065	0·09	0·11
11	0·095	0·105	0·07	0·05	0·10	0·08	0·08	0·075	0·08	0·10
10	0·09	0·130	0·07	0·06	0·085	0·09	0·08	0·08	0·08	0·10
9	0·09	0·125	0·07	0·055	0·09	0·10	0·07	0·07	0·08	0·10
8	0·10	0·14	0·07	0·07	0·095	0·095	0·08	0·08	0·085	0·10
7	0·105	0·13	0·08	0·07	0·09	0·110	0·08	0·11	0·085	0·11
6	0·11	0·11	0·07	0·06	0·09	0·115	0·08	0·10	0·09	0·11
5	0·13	0·12	0·08	0·065	0·10	0·13	0·09	0·10	0·08	0·11
4	0·135	0·11	0·07	0·06	0·10	0·14	0·10	0·10	0·09	0·12
3	0·145	0·12	0·08	0·07	0·11	0·14	0·11	0·12	0·11	0·12
2	0·155	0·14	0·11	0·07	0·12	0·16	0·11	0·14	0·11	0·13
1	0·20	0·19	0·145	0·08	0·24	0·24	0·16	0·27	0·16	0·17
Fracture	0·40	0·37	0·16	0·11	0·42	0·48	0·29	0·48	0·35	0·44
1	0·24	0·21	0·09	0·08	0·19	0·1	0·255	0·16	0·30	0·28
2	0·16	0·15	0·09	0·07	0·11	0·14	0·165	0·12	0·13	0·15
3	0·12	0·13	0·09	0·06	0·09	0·12	0·11	0·07	0·12	0·12
4	0·115	0·12	0·08	0·05	..	0·11	0·11	..	0·11	0·12
5	0·105	0·13	0·07	0·06	..	0·10	0·09	..	0·08	0·11
6	0·09	0·12	0·06	0·06	..	0·09	0·09	..	..	0·11
7	0·09	0·12	..	0·04	..	0·08	0·095	..	..	0·11
8	0·07	0·11	..	..	..	..	0·085	..	..	0·10
9	0·07	0·11	..	..	..	..	..	..	..	..
10	0·07	0·10	..	..	..	..	..	..	..	..
11	0·07	0·10	..	..	..	..	..	..	..	..
12	0·07	0·07	..	..	..	..	..	..	..	..

TABLE XIII.—ROTHERHAM STEEL BOILER-PLATES—*continued*.

EXTENSIONS IN EACH HALF-INCH.

No.	2396	2397	2398	2399	2400	2401	2402	2403	2404	2405
Area	0·9502	0·9812	0·5830	0·5815	0·6074	0·5845	0·4948	0·4889	0·5237	0·5239
18	0·095	0·08	..	..	..	..	..	..	..	..
17	0·10	0·075	..	..	..	..	..	..	..	..
16	0·105	0·085	..	..	..	..	..	..	..	..
15	0·11	0·075	..	..	..	..	..	..	0·09	..
14	0·11	0·085	..	..	..	..	..	..	0·105	0·05
13	0·10	0·085	..	..	0·09	0·08	..	..	0·085	0·04
12	0·09	0·08	..	..	0·095	0·08	0·06	..	0·08	0·07
11	0·095	0·075	..	0·08	0·10	0·09	0·06	..	0·06	0·06
10	0·085	0·08	0·09	0·11	0·115	0·08	0·06	..	0·06	0·055
9	0·095	0·09	0·10	0·09	0·12	0·08	0·06	0·06	0·06	0·045
8	0·10	0·10	0·09	0·09	0·12	0·09	0·06	0·085	0·05	0·045
7	0·105	0·10	0·10	0·09	0·10	0·095	0·065	0·085	0·045	0·045
6	0·11	0·115	0·11	0·10	0·14	0·095	0·075	0·105	0·045	0·04
5	0·11	0·11	0·11	0·10	0·08	0·10	0·07	0·115	0·06	0·045
4	0·11	0·11	0·12	0·105	0·14	0·09	0·08	0·10	0·055	0·045
3	0·11	0·125	0·12	0·115	0·105	0·115	0·09	0·105	0·075	0·05
2	0·12	0·16	0·13	0·11	0·15	0·125	0·105	0·11	0·07	0·08
1	0·17	0·30	0·19	0·24	0·15	0·21	0·145	0·135	0·11	0·14
Fracture	0·41	0·32	0·47	0·32	0·43	0·34	0·40	0·42	0·27	0·36
1	0·24	0·16	0·18	0·14	0·16	0·12	0·14	0·195	0·19	0·115
2	0·14	0·12	0·13	0·105	0·13	0·10	0·10	0·115	0·10	0·065
3	0·125	0·11	0·11	0·095	0·10	0·09	0·085	0·09	..	0·05
4	0·105	0·11	0·10	0·09	0·10	0·08	0·08	0·09	..	..
5	0·09	0·12	0·10	0·09	..	..	..	0·07	..	..
6	0·06	0·12	0·08	0·07	..	..	..	0·07	..	..
7	..	0·11	0·07	..	..	..	..	0·07	..	..
8	..	..	..	..	..	..	..	0·07	..	..
9	..	..	..	..	..	..	..	..	..	..
10	..	..	..	..	..	..	..	..	..	..
11	..	..	..	..	..	..	..	..	..	..
12	..	..	..	..	..	..	..	..	..	..

TABLE XIV.—ROTHERHAM STEEL BOILER-PLATES.

TOTAL ELONGATION IN DIFFERENT GAUGE-LENGTHS. FRACTURE AT MIDDLE OF GAUGE-LENGTH.

No. of Test-Bar.	2386	2387	2390	2391	2394	2395	2398	2399	2402	2403
Area of Section .	1·2931	1·2976	1·3159	1·3270	0·9327	0·9756	0·5830	0·5815	0·4948	0·4889
Value of $\frac{l}{\sqrt{A}}$ for 8 inches gauge-length . . .	7·0	7·0	7·0	7·0	8·3	8·1	10·5	10·5	11·4	11·4
	Cut Lengthways of Plate.									
In 2 inches .	0·997	0·915	0·965	1·060	0·930	1·030	0·970	0·807	0·787	0·862
„ 4 „ . . .	1·514	1·425	1·380	1·595	1·380	1·530	1·440	1·221	1·144	1·264
„ 6 „ . . .	2·004	1·905	1·770	2·052	1·730	1·980	1·855	1·593	1·439	1·631
„ 8 „ . . .	2·384	2·395	2·135	2·439	2·075	2·410	2·210	1·948	1·704	1·950
„ 10 „ . . .	2·709	2·870	2·495	2·824	2·400	2·810	2·590	2·328	1·944	..
„ 12 „ . . .	3·036	3·277	2·880	3·159	2·730	3·220	..	..	2·184	..
„ 14 „ . . .	3·338	3·654	3·290	3·474	3·115	3·630	..	..	..	..
„ 16 „ . . .	..	..	3·720	3·754	3·565	4·010	..	..	..	..
„ 18 „ . . .	..	..	4·060	4·024	..	..	..	..	..	..

TABLE XIV.—*continued.*

No. of Test-Bar.	2388	2389	2392	2393	2396	2397	2400	2401	2404	2405
Area of Section.	1·2779	1·2767	1·3368	1·2390	0·9502	0·9812	0·6074	0·5845	0·5237	0·5239
Value of $\frac{l}{\sqrt{A}}$ for 8 inches gauge-length . . .	7·1	7·1	7·0	7·2	8·2	8·1	10·3	10·5	11·0	11·0
Cut Across the Plate.										
In 2 inches. . .	0·495	0·340	0·842	1·040	0·950	0·920	0·088	0·782	0·655	0·687
„ 4 „ . . .	0·840	0·595	1·304	1·460	1·422	1·405	1·345	1·184	0·945	0·904
„ 6 „ . . .	1·130	0·835	1·674	1·860	1·814	1·852	1·765	1·564	1·165	1·079
„ 8 „ . . .	1·425	1·105	2·016	2·260	2·209	2·289	2·225	1·939	1·350	1·254
„ 10 „ . . .	1·705	1·345	2·318	2·560	2·581	2·649	2·700	2·269	1·580	1·444
„ 12 „ . . .	1·965	1·555	2·628	2·855	2·949	2·959	3·110	2·609	1·840	1·689
„ 14 „ . . .	2·195	1·755	2·880	3·155	3·349	3·294	..	..	2·215	1·889
„ 16 „ . . .	2·450	1·995	3·188	3·450	3·784	3·614	..	..	..	..
„ 18 „ . . .	2·765	2·215	3·438	3·740	..	..	..	..	..	..

TABLE XV.—ROTHERHAM STEEL BOILER-PLATES.

PER CENT. OF ELONGATION IN DIFFERENT GAUGE-LENGTHS.

FRACTURE IN MIDDLE OF GAUGE-LENGTH.

No. of Test-Bar.	2386	2387	2390	2391	2394	2395	2398	2399	2402	2403
					Cut Lengthways of Plate.					
In 2 Inches . .	49·9	45·8	48·3	53·0	46·5	51·5	48·5	40·4	39·4	43·1
„ 4 „ . .	38·6	35·6	34·5	39·9	34·5	38·2	36·0	30·5	28·6	31·6
„ 6 „ . .	33·4	31·7	29·5	34·2	28·9	33·0	30·9	26·6	24·0	27·2
„ 8 „ . .	29·8	29·9	26·9	30·5	25·9	30·1	27·6	24·4	21·3	24·4
„ 10 „ . .	27·1	28·7	25·0	28·2	24·0	28·1	25·9	23·3	19·4	..
„ 12 „ . .	25·3	27·3	24·0	26·3	22·7	26·8	..	..	18·2	..
„ 14 „ . .	23·8	26·1	23·5	24·8	22·3	25·9	..	..	..	..
„ 16 „ . .	..	..	23·3	23·5	22·3	25·1	..	..	..	..
„ 18 „ . .	..	..	22·5	22·3	..	..	..	..	..	..

TABLE XV.—ROTHERHAM STEEL BOILER-PLATES—*continued*.

PER CENT. OF ELONGATION IN DIFFERENT GAUGE-LENGTHS.

FRACTURE IN MIDDLE OF GAUGE-LENGTH.

No. of Test-Bar .	2388	2389	2392	2393	2396	2397	2400	2401	2404	2405
					Cut Across the Plate.					
In 2 inches. .	24·8	17·0	42·1	52·0	47·5	46·0	44·0	39·1	32·8	34·4
„ 4 „ . .	21·0	14·9	32·6	36·5	35·6	35·1	33·6	29·6	23·6	22·6
„ 6 „ . .	18·9	13·9	27·9	31·0	30·2	31·0	29·4	26·1	19·4	17·9
„ 8 „ . .	17·8	13·8	26·5	28·3	27·6	28·6	27·8	24·2	16·9	15·7
„ 10 „ . .	17·1	13·5	23·2	25·6	25·8	26·5	27·0	22·7	15·8	14·4
„ 12 „ .	16·4	13·0	21·9	23·8	24·6	24·6	25·9	21·7	15·3	14·1
„ 14 „ . .	15·7	12·5	20·6	22·5	23·9	23·5	..	..	15·8	13·5
„ 16 „ . .	15·3	12·5	19·9	21·5	23·7	23·6	..	..	..	..
„ 18 „ . .	15·4	12·3	19·1	20·8	..	..	..	..	..	..

APPENDIX II.

Tests of Some Plates with Varying Percentages of Carbon, received from the Park Gate Iron and Steel Works, Rotherham.

Mr. F. W. Dick was good enough to send some test-bars from plates with varying percentages of carbon (0·32 per cent. to 0·60 per cent.). These have been tested similarly to the others, and are interesting as showing the variation of strength and elongation with increase of carbon. Half the bars were unannealed and half annealed.

Two of the unannealed bars broke anomalously, one with a very low strength from some flaw or internal stress, the other outside the gauge-marks, so that the measurements of elongation are useless.

Table XVI.—Rotherham Steel Plates with Different Percentages of Carbon.

General Results.

Unannealed Plates.

Test No.	Mark.	Per Cent. of Carbon.	Dimensions in Inches. Width.	Thickness.	Area.	Breaking Stress in Tons per Square Inch.	Mean Breaking Stress.	Elongation in 8 Inches per Cent.	Mean Elongation.
2423	3	0·32	1·483	0·2785	0·413	35·62		17·7	
2421	3	0·32	1·485	0·5110	0·759	33·85	33·97	21·9	20·0
2419	3	0·32	0·993	0·7390	0·738	32·43		20·4	
2416	4	0·48	1·479	0·2615	0·387	39·41		15·8	
2415	4	0·48	1·468	0·5150	0·756	38·45	38·09	16·1	16·0
2413	4	0·48	0·979	0·7575	0·742	36·42		16·0	
2411	5	0·60	1·491	0·2720	0·406	47·39	47·25	13·8	
2409	5	0·60	1·493	0·5080	0·758	47·10		..	13·8
2407	5	0·60	0·989	0·7580	0·750	..	..	..	

Table XVII.—Rotherham Steel Plates with Different Percentages of Carbon.

General Results.

Annealed Plates.

Test No.	Mark.	Per Cent. of Carbon.	Dimensions in Inches. Width.	Thickness.	Area.	Breaking Stress in Tons per Square Inch.	Mean Breaking Stress.	Elongation in 8 Inches per Cent.	Mean Elongation.
2422	3A	0·32	1·479	0·2810	0·416	29·85		23·6	
2420	3A	0·32	1·483	0·5130	0·761	30·43	30·33	22·4	22·0
2418	3A	0·32	0·992	0·7300	0·724	30·72		20·0	
2417	4A	0·48	1·487	0·2620	0·390	34·03		19·4	
2414	4A	0·48	1·486	0·5075	0·754	33·38	33·46	21·6	20·3
2412	4A	0·48	0·989	0·7600	0·752	32·98		19·8	
2410	5A	0 60	1·492	0·2710	0·404	40·94		16·9	
2408	5A	0·60	1·494	0·5090	0·760	38·78	39·23	17·9	17·3
2406	5A	0·60	0·995	0·7620	0·758	37·98		17·0	

TABLE XVIII.—STEEL PLATES WITH VARYING PERCENTAGES OF CARBON.
EXTENSIONS IN EACH HALF-INCH.

Unannealed Plates.

Test No.	2423	2421	2419	2416	2415	2413	2411	2409	2407
Area.	0·413	0·759	0·738	0·387	0·756	0·742	0·406	0·758	0·750
Per Cent. of Carbon	0·32	0·32	0·32	0·48	0·48	0·48	0·60	0·60	0·60
..	..	..	..	..	..	..	..	0·02	..
..	..	..	..	..	..	..	..	0·025	..
14	0·04	..	..	0·06	..	0·04	0·04	0·03	..
13	0·03	..	..	0·085	..	0·035	0·045	0·015	..
12	0·03	..	..	0·06	..	0·045	0·045	0·03	..
11	0·03	0·07	..	0·05	..	0·04	0·03	0·03	..
10	0·04	0·07	..	0·045	0·03	0·04	0·05	0·03	..
9	0·04	0·07	0·07	0·04	0·03	0·03	0·03	0·02	..
8	0·05	0·07	0·075	0·05	0·04	0·04	0·03	0·02	..
7	0·06	0·07	0·065	0·04	0·03	0·04	0·04	0·025	..
6	0·06	0·07	0·075	0·06	0·04	0·04	0·05	0·02	..
5	0·07	0·07	0·07	0·05	0·04	0·05	0·07	0·03	..
4	0·06	0·09	0·065	0·06	0·05	0·06	0·05	0·025	..
3	0·07	0·10	0·08	0·05	0·06	0·07	0·07	0·025	..
2	0·07	0·12	0·095	0·07	0·08	0·08	0·08	0·035	
1	0·11	0·21	0·14	0·09	0·10	0·12	0·15	0·02	
Fracture	0·31	0·34	0·35	0·21	0·29	0·29	0·16	..	..
1	0·15	0·12	0·165	0·20	0·18	0·14	0·08	..	..
2	0·09	0·10	0·105	0·09	0·08	0·09	0·06	..	..
3	0·065	0·09	0·085	0·08	0·06	0·07	0·05	..	..
4	..	0·09	0·065	..	0·06	..	..	Broke outside gauge marks.	..
5	..	0·08	0·07	..	0·06	..	..		Broke at a flaw.
..	..	0·07	0·07	..	0·07	..	..		
..	..	..	0·06	..	0·05	..	..		
..	..	..	0·06	..	..	..	..		

TABLE XIX.—ROTHERHAM STEEL PLATES WITH VARYING PERCENTAGES OF CARBON.
EXTENSIONS IN EACH HALF-INCH.
Annealed Plates.

Test No.	**2422**	**2420**	**2418**	**2417**	**2414**	**2412**	**2410**	**2408**	**2406**
Area.	0·416	0·761	0·724	0·390	0·754	0·752	0·404	0·760	0·758
Per Cent. of Carbon	0·32	0·32	0·32	0·48	0·48	0·48	0·60	0·60	0·60
16	..	..	..	0·075	..	..	..	..	..
15	..	..	..	0·075	..	..	..	..	..
14	..	0·055	0·05	0·10	..	..	0·05	..	..
13	..	0·085	0·06	0·095	0·05	..	0·04	..	..
12	0·07	0·055	0·05	0·085	0·055	0·06	0·04	..	..
11	0·06	0·07	0·08	0·07	0·05	0·06	0·05	..	..
10	0·07	0·07	0·06	0·075	0·06	0·06	0·05	..	0·04
9	0·08	0·07	0·06	0·055	0·055	0·055	0·05	0·09	0·04
8	0·09	0·08	0·07	0·07	0·08	0·055	0·05	0·07	0·04
7	0·09	0·075	0·06	0·08	0·08	0·05	0·05	0·07	0·05
6	0·09	0·08	0·07	0·09	0·08	0·065	0·06	0·07	0·05
5	0·09	0·08	0·07	0·07	0·09	0·075	0·10	0·07	0·07
4	0·10	0·10	0·06	0·07	0·10	0·08	0·09	0·07	0·07
3	0·10	0·09	0·09	0·08	0·09	0·10	0·08	0·08	0·08
2	0·11	0·12	0·10	0·09	0·11	0·11	0·08	0·08	0·10
1	0·18	0·16	0·11	0·15	0·18	0·19	0·14	0·10	0·11
Fracture.	0·30	0·36	0·30	0·27	0·30	0·29	0·18	0·20	0·20
1	0·13	0·12	0·19	0·10	0·13	0·12	0·10	0·17	0·15
2	0·12	0·11	0·12	..	0·09	0·09	0·06	0·10	0·10
3	0·11	0·08	0·10	..	0·07	0·08	0·06	0·09	0·08
4	0·10	..	..	..	0·08	0·08	..	0·08	0·09
5	0·10	..	..	..	..	..	..	0·06	0·08
6	..	..	..	..	..	..	..	0·06	0·07
7	..	..	..	..	..	..	..	0·07	0·08
8	..	..	..	..	..	..	..	0·05	..

TABLE XX.—ROTHERHAM STEEL PLATES WITH VARYING PERCENTAGES OF CARBON.

TOTAL ELONGATION IN DIFFERENT GAUGE-LENGTHS.

Unannealed.

Test No.	2423	2421	2419	2416	2415	2413	2411
Per cent. of carbon .	0·32	0·32	0·32	0·48	0·48	0·48	0·60
Area	0·413	0·759	0·738	0·387	0·756	0·742	0·406
Value of $\frac{l}{\sqrt{A}}$ for 8 inches gauge-length	12·45	9·18	9·31	12·86	9·20	9·29	12·56
In 2 inches. . .	0·65	0·78	0·76	0·58	0·65	0·64	0·46
„ 4 „	0·93	1·17	1·09	0·85	0·91	0·92	0·70
„ 6 „	1·19	1·47	1·36	1·07	1·12	1·12	0·94
„ 8 „	1·42	1·75	1·63	1·26	1·29	1·28	1·10
„ 10 „	1·59	2·03	..	1·44	1·42	1·42	1·24
„ 12 „	1·72	..	..	1·64	..	1·59	1·40
„ 14 „	1·85	..	..	1·93	..	1·74	1·57

TABLE XXI.—ROTHERHAM STEEL PLATES WITH VARYING PERCENTAGES OF CARBON.

TOTAL ELONGATIONS IN DIFFERENT GAUGE-LENGTHS.

Annealed.

Test No.. .	2422	2420	2418	2417	2414	2412	2410	2408	2406
Per cent. of carbon . .	0·32	0·32	0·32	0·48	0·48	0·48	0·60	0·60	0·60
Area . . .	0·416	0·761	0·724	0·390	0·754	0·752	0·404	0·760	0·758
Value of $\frac{l}{\sqrt{A}}$ for 8 inches gauge-length. .	12·40	9·17	9·41	12·81	9·21	9·22	12·59	9·18	9·18
In 2 inches	0·73	0·76	0·71	0·61	0·71	0·70	0·49	0·56	0·56
„ 4 „ .	1·15	1·14	1·07	0·93	1·06	1·06	0·79	0·90	0·90
„ 6 „ .	1·53	1·48	1·34	1·23	1·41	1·36	1·14	1·17	1·19
„ 8 „ .	1·89	1·79	1·60	1·55	1·73	1·58	1·35	1·43	1·36
„ 10 „ .	2·21	2·08	1·85	1·81	1·98	1·80	1·55	..	1·52
„ 12 „ .	2·47	2·35	2·12	2·11	2·20	2·04	1·74	..	..
„ 14 „ .	..	2·63	2·34	2·48	..	..	1·91	..	..

TABLE XXII.—ROTHERHAM STEEL PLATES WITH DIFFERENT PERCENTAGES OF CARBON.

ELONGATION PER CENT. IN DIFFERENT GAUGE-LENGTHS.

Unannealed.

Test No. . .	2423	2421	2419	2416	2415	2413	2411
Carbon per cent.	0·32	0·32	0·32	0·48	0·48	0·48	0·60
In 2 inches	32·5	39·0	38·0	29·0	32·5	32·0	23·0
„ 4 „ .	23·2	29·2	27·2	21·2	22·8	23·0	17·5
„ 6 „ .	19·8	24·5	22·7	17·8	18·7	18·7	15·7
„ 8 „ .	17·8	21·9	20·4	15·8	16·1	16·0	13·8
„ 10 „ .	15·9	20·3	..	14·4	14·2	14·2	12·4
„ 12 „ .	14·3	..	..	13·7	..	13·3	11·7
„ 14 „ .	13·2	..	..	13·8	..	12·4	11·2

Annealed.

Test No. . .	2422	2420	2418	2417	2414	2412	2410	2408	2406
Carbon per cent.	0·32	0·32	0·32	0·48	0·48	0·48	0·60	0·60	0·60
In 2 inches	36·5	38·0	35·5	30·5	35·5	35·0	24·5	28·0	28·0
„ 4 „ .	28·7	28·5	26·7	23·2	26·5	26·5	19·7	22·5	22·5
„ 6 „ .	25·5	24·7	22·3	20·5	23·5	22·7	19·0	19·5	19·8
„ 8 „ .	23·6	22·4	20·0	19·4	21 6	19·8	16·9	17·9	17·0
„ 10 „ .	22·1	20·8	18·5	18·1	19·8	18·0	15·5	..	15·2
„ 12 „ .	20·6	19·9	17·7	17·6	18·3	17·0	14·5	..	..
„ 14 „ .	..	18·8	16·7	17·7	..	..	13·6	..	..

TABLE XXIII.—MEAN DIFFERENCE BETWEEN UNANNEALED AND ANNEALED BARS.

Percentage of Carbon.	Breaking Stress. Tons per Square Inch.		Difference.	Elongation in 8 Inches per Cent.		Difference.
	Unannealed.	Annealed.		Unannealed.	Annealed.	
0·32	33·97	30·33	3·64	20·0	22·0	2·0
0·48	38·09	33·46	4·63	16·0	20·3	4·3
0·60	47·25	39·23	8·02	13·8	17·3	3·5

The difference between unannealed and annealed plates increases with the percentage of carbon. Taking the differences in per cent. of the values for annealed plates they are:—

Carbon °/o	Difference of annealed and unannealed.	
	Strength.	Elongation.
0·32	12·0	9·1
0·48	13·9	21·1
0·60	20·4	20·2

APPENDIX III.

If the elongations for more than two gauge-lengths have been determined, for instance, by measuring the extensions of ½-inch lengths, then the values of the constants in the elongation equation are best determined by the method of least squares. The elongation equation is—

$$e\% = \frac{c\sqrt{A}}{l} + b$$

For simplicity, let $\frac{\sqrt{A}}{l} = a$, and suppose the elongations have been observed for n gauge lengths. Then the most probable values of the constants are given by the equations—

$$c = \frac{n\Sigma ea - \Sigma e \Sigma a}{n\Sigma a^2 - (\Sigma a)^2}$$

$$b = \frac{\Sigma e \Sigma a^2 - \Sigma ea \Sigma a}{n\Sigma a^2 - (\Sigma a)^2}$$

Thus for bars 2398–9, $A = 0\cdot5822$, $n = 4$.

l	a	$e\%$	ea	a^2
4	0·1907	33·3	6·351	0·03637
6	0·1271	28·8	3·661	0·01615
8	0·0954	25·9	2·471	0·00910
10	0·0763	24·6	1·876	0·00582
	$\Sigma =$ 0·4895	112·6	14·359	0·06744

$(\Sigma a)^2 = 0\cdot2396.$

$$c = \frac{4 \times 14\cdot359 - 112\cdot6 \times 0\cdot4895}{4 \times 0\cdot06744 - 0\cdot2396} = 76\cdot83$$

$$b = \frac{112\cdot6 \times 0\cdot06744 - 14\cdot359 \times 0\cdot4895}{4 \times 0\cdot06744 - 0\cdot2396} = 18\cdot64$$

A simpler method was used in finding the values of c and b given in the Paper, but the method above is the least open to objection.

APPENDIX IV.

The following constants for some other metals are interesting:—

Gunmetal (cast) . . . . $e\% = \frac{8\cdot3\sqrt{A}}{l} + 10\cdot6$

Rolled Brass . . . . $e\% = \frac{101\cdot6\sqrt{A}}{l} + 9\cdot7$

Rolled Copper . . . . $e\% = \frac{84\sqrt{A}}{l} + 0\cdot8$

Annealed Copper . . . . $e\% = \frac{125\sqrt{A}}{l} + 35$

The difference between the constants for the hard rolled copper bar and a similar bar annealed is interesting.

[Discussion.

Discussion.

The President. The PRESIDENT, in moving a vote of thanks to the Author for his Paper, remarked that it added another to the many experimental researches which the Author had conducted with so much ability, and which were of the utmost value to all engineers. The subject, which had long exercised the minds of engineers, was dealt with very fully. In an important Paper read before the Institution of Naval Architects in 1895, it had been shown[1] that, by simply varying the sectional area of bars of the same length, it was possible, with material of the same quality, to pass from 24 per cent. of elongation in a length of 2 inches to 47 per cent. The members owed much to the Author and to the Engineering Standards Committee for taking up the matter again in a thorough way. He hoped it might lead to some practical result; because all must agree with the Author that it was very desirable to have some uniformity of test-conditions that would secure comparability in the results of ductility-tests. He fully concurred in the Author's view that, from the engineer's side, chemical composition had better be left alone. In all the years during which he had had to do with the supervision of steel-manufacture for shipbuilding purposes for the Admiralty, that was a principle on which he had insisted. In the case of armour, or material of that nature, where the composition was of the highest importance, and where mechanical tests and firing-tests could not be carried out on every sample, it was no doubt the duty of those charged with the supervision of the manufacture to see that the chemical composition of the material was the same throughout; but in general, in regard to steel for structural purposes, the Author said the right thing when he stated that engineers, as such, had to do with mechanical properties, and that it was not their business to specify chemical composition or modes of manufacture. He also agreed with the Author that, from the engineer's side, the essential things were to specify the minimum strength which would be accepted, and the amount of ductility which would be insisted upon; and not to cramp the manufacturer on the side of maximum strength. That also was a principle which for many years had been worked to by the Admiralty; and the only meaning

[1] Transactions Inst. Naval Architects, vol. xxxvi. p. 273.

of the upper limit of tensile strength in an Admiralty specification was that the resident overseer was not trusted to say absolutely what should be accepted, but had to refer cases of that kind to be dealt with by a central authority. In practice the Admiralty did not reject steel because it was stronger than the upper limit specified, and he did not see why anybody else should do so, provided the ductility was assured. About 28 years ago, when mild steel was first coming into use for shipbuilding, he had carried out, in conjunction with the representatives of Messrs. Siemens, a large series of tests at Landore, in which the elongation in each unit of length in the gauge-length of the test-pieces was measured; and they had been greatly impressed with the flow of the metal that took place near the point of rupture, and the high percentage of the total elongation in the unit of length wherein fracture occurred. Now the Author had put that into what seemed to be a promising formula, and had made proposals which were of much practical value, and which, he hoped, would be thoroughly discussed, and have some effect upon future testing. In practice, niceties of difference between percentages of elongation, when dealing with material which, at the worst, was extremely ductile, did not much concern the practical engineer; that was to say, that, as between 24 per cent. and 26 per cent., if 24 per cent. was obtained, engineers were not afraid of using the material: but for scientific purposes and for standard testing there could be no doubt that the suggestions of the Author were of the utmost value. He hoped the discussion would have a wide range. The Author had introduced the subject of the use of steel of higher tensile strength, and was not afraid of such material. Neither was the President. It had been in use in the Admiralty service for some years with very beneficial results. The President.

The Author thought the examples of instruments used in the testing-laboratory, which he had placed on the table, might interest some of the younger members. All of them were instruments which had been designed for use in the laboratory of the Central Technical College, and every one of them had some novel feature [1]. It was mentioned in the Paper that the extreme case of irregularity of distribution of elongation in a long bar occurred when two local contractions were formed in the same bar. It occurred very rarely, but it did occur; and, oddly enough, within the last fortnight Mr. Dick, of Rotherham, in making some tests, had met with a case. The steel bar tested by Mr. Dick was on the The Author.

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[1] Some particulars of these instruments will be found at p. 266.—Sec. Inst. C.E.

The Author. table. It had broken at one local contraction and had, in addition, a second well-marked local contraction. The gauge-length of the bar was about 8 inches, and neither of the contractions was very near to the end. Mention was also made in the Paper of the importance of the position of the fracture on the percentage of elongation. Within the past week there had come to him a test-sheet, recording about twenty carefully-made tests, from the works of Messrs. Charles Cammell & Co., and at least three out of the twenty results were anomalous. There were two bars of 6-inch gauge-length and ½ square inch area, one of which gave 17¾ per cent. elongation and the other 10 per cent. If this result were attributed to a difference in the material, it would be very important; but it was almost impossible to attribute it to that cause, because the two bars had been cut from the same forging, side by side. It so happened that Mr. Fairholme had noted on which inch-length of the bar the fracture occurred, and on looking into the three anomalous cases it had been detected at once that, in the bars with the small elongation, fracture occurred within the inch nearest the gauge-point. The difference between 17¾ per cent. and 10 per cent. elongation was considerable, and he thought it was probably explained by the position of the fracture. When such anomalies occurred in test-sheets, they were injurious both to the steel-maker and to the steel-user, unless some explanation of them could be found; and he had attempted in the Paper to point out the sources of anomalies of that kind occurring in ordinary test-sheets. He had avoided saying anything about test-specifications for steel, which was a matter for more practical engineers; but he hoped that point, among others, would be dealt with in the discussion.

Dr. Kennedy. Dr. Alex. B. W. Kennedy, Vice-President, observed that, as one who had tested many thousand pieces of iron and steel, he had read the Paper with much interest, and he believed that out of it would come results which would be of really practical importance. The Author alluded at the beginning of the Paper to tests other than tensile, although his Paper had nothing to do with them. For many purposes what might be called the mechanical tests—the drop-test on rails, the bending-test with bars, and the squeezing-test with pieces cut off tubes, etc.—were of great importance; but he did not think they could, at least for a long time, supersede the ordinary test which gave the tenacity and ductility, or at any rate the extensibility, of the material itself. It was therefore perfectly justifiable, on the part of the Author, to devote the whole of the Paper to the consideration

of that particular kind of test. The difficulty that presented itself to all who had to use tests was just the one which the Paper was designed to meet. For instance, in the case of a boiler it was specified that the steel was to have a certain tenacity, and a certain extensibility in a given length; but of course there were two, and possibly three or four, different thicknesses of plate in a boiler, which might range from ½ inch in the furnace to 1 inch or 1½ inch in the shell; and very different figures were obtained for the relative values of the length and the square root of the cross-sectional area, and very different extensibilities were found on test. It was always a puzzle to any one who had to deal with matters of that kind to know how to allow for such differences. He believed that was exactly the point which was dealt with in the Paper, and he hoped to be able to work out from it the exact application of the Author's views to cases which were the most troublesome or most difficult in practice. With regard to the causes of the singularly irregular results in extensibility, the occurrence of fracture close to the end of the test-piece was one which was quite recognizable, and when the test-piece was seen, allowance was made for it as a matter of course. He would much like to hear, however, the Author's views as to the more difficult case met with in the testing of thin materials, where the metal tore from one side first. In the Paper the Author had rejected all such cases, and for his purposes it was obviously necessary to reject them; but if a test-sheet was found to contain half a dozen or a dozen tests, and one of those tests was irregular in that way, it was always a little uncertain whether the test or the plate should be rejected. In practice, the test was generally rejected. He desired to know how far there was any indication that the local inequality in a strip cut from a plate could often be so great as to determine the starting of the fracture at one side of the bar, which of course gave a low extension in any case, and often affected the tensile strength also. He would also value greatly the Author's opinion as to the extent to which, under ordinary circumstances, defective gripping of the plate might cause that particular kind of fracture. No doubt, if the plate were distinctly thicker on one edge than the other, the grip in some machines would be uneven; which might be, and probably was, sufficient to cause great irregularities of that kind. Of course he referred to tests which came from the works, not to the check tests of the laboratory. He imagined that in practice the result was that most engineers rejected those particular tests, and accepted the plates from which they came, unless there were other reasons (*e.g.*, from

Dr. Kennedy.

Dr. Kennedy. examination of the fracture) for thinking that the metal itself was defective, as often happened. The actual fracture had always to be looked at in any difficult cases: it was a matter which did not fall within the scope of the Paper, but it decided in cases of irregularity whether the result represented by the particular test could be accepted or not. The Author's statement that, the cross-sectional area and the length being constant, the exact form of the cross section did not appear to affect greatly the elongation, was certainly indicated by his own results. If the Author, from his experience, could give some idea of the limitations within which that was true, it would be of great value. In practice the difficulty usually arose only with wide sections of very thin material, such as was used for tubes. Perhaps at the other extreme it might arise where it was necessary to have very narrow pieces of very thick plate. In the very thin pieces, such, for instance, as might be obtained by comparing a piece $\frac{1}{8}$ inch by 4 inches with $\frac{1}{2}$ inch by 1 inch, the relation of the perimeter to the length might come in. But those were exceptional cases, and, fortunately, had not often to be dealt with. As he understood the Paper, the actual results of the tests on which it was based, and which, he noticed, were specially designed to give the greatest possible variety of results, were those given in the Appendixes, and the Tables in the Paper were not special results, but results deduced from plotted diagrams. [The AUTHOR assented.] There was one point which had puzzled him, and which was not explained. Taking the Table referring to ship-plates on page 186, there was a series of results for bars of $\frac{1}{2}$ square inch area, and one of them was $\frac{3}{8}$ inch thick and the other $1\frac{1}{4}$ inch thick. They gave very different mean elongations from the diagrams; but, of course, they were not only of the same area practically but of the same shape.

The AUTHOR remarked that probably the structure of the thick plates was different from that of the thin plates, though the composition was the same. All the thick plates were less ductile than the thin, until the thickness was below $\frac{3}{8}$ inch.

The President. The PRESIDENT asked whether there was any information as to the amount of work put upon the plates.

The Author. The AUTHOR said they were ordinary ship-plates that were being supplied for ships.

Dr. Kennedy. Dr. KENNEDY was glad to receive the Author's explanations of a point which had rather puzzled him. Finally, he was much struck with the following passage in the Paper (p. 197):—"A criticism may be anticipated, namely, that the differences of elongation shown are small and therefore not significant. But in

the Author's opinion, the ordinary methods of testing with dissimilar bars in which considerable differences of elongation are found for practically similar material—differences which, of course, are not of any significance—have obscured the fact that even small differences of elongation would be significant if testing were not so roughly and unscientifically carried on." If the use of the Author's formulas, or anything based upon them, allowed such a result to be arrived at as was here suggested, so that the ductility of different pieces of metal of different sections could be compared in such a way that even small differences were rendered significant, it would be a matter of the utmost importance to engineers who had to specify, and also one of great scientific interest to the physicist. Dr. Kennedy.

Dr. FRANCIS ELGAR considered the Paper to be full of valuable data and useful suggestions for all who had to do with the testing of steel. Speaking as a shipbuilder, he would say that there were points in it which touched closely upon shipbuilding work, and upon the manufacture of steel for marine boilers. The Author had stated that he did not intend to offer any suggestions as to the modification of present practice; but it seemed to Dr. Elgar that the Paper was pregnant with suggestions, and he thought that every one who had to do with the testing of ship- and boiler-steel would do well to study it carefully, with a view to adopting some of the suggestions which certainly were implied, even if they were not directly made by the Author with the object of advocating practical reforms. He agreed entirely with the Author and the President that engineers did not require to concern themselves much with the question of the composition of the steel they decided to employ, but rather with that of the mechanical properties it could be proved to possess by means of a well-organized system of testing. If the results of mechanical tests proved unsatisfactory, the cause was a practical question to be dealt with by the steel-manufacturer rather than by the engineer or the user of the material. One of the most important points referred to was, that the first consideration in attempting to determine the mechanical properties of steel was that the tests applied should be strictly comparable. In research work that was very necessary, especially in testing new alloys of steel, as stated in the Paper; but he thought it was no less important that the results of testing should be as closely comparable as possible for ordinary ship- or boiler-steel, considering that such tests were made by separate official bodies, like the Admiralty, the Board of Trade, and the various classification societies, so Dr. Elgar.

Dr. Elgar. that sometimes there were two or three different sets of officials making independent tests of the same steel. It was particularly important in such cases that the tests should be made on a basis that would render them exactly comparable. At present there was certainly room for improvement in that respect; for not only were the tests not always comparable with reference to tensile strength, on account of want of agreement between the various testing bodies as to exactly what tensile tests the steel should bear, but there were also variations in the size and form of the test-pieces. Shipbuilders and marine engineers had been anxious for a long while that the practice in the testing of steel by the various official bodies should be assimilated; and he hoped that one result of the Paper would be to draw attention to the importance of that matter, and to cause the present differences in testing to be eliminated. He had reason to believe that it was under the consideration of the Engineering Standards Committee to recommend standard tests for ship-steel and boiler-steel, and standard sizes and forms of test-pieces. He thought details of that kind were better left in the hands of such a body as the Committee; and he hoped that any recommendation they might make upon the subject would be adopted forthwith by the authorities who regulated the testing of steel. He also agreed with the Author and the President in thinking that all that it was necessary to do in ordinary cases in ship-steel and boiler-steel was to specify a certain minimum strength, and also a percentage of elongation as the measure of ductility, but not to lay down any hard-and-fast rule with reference to the superior limit of strength. He did not see why, provided sufficient ductility was obtained in a plate, there should be any objection to its also having higher tensile strength than the official regulations now allowed. The question of the use of steel of higher tensile strength was becoming of great importance to shipbuilders and marine engineers, because, in the construction of large and fast steamers, limited in draught of water as they often were, it was important to get material of greater strength, in order to be able to make still further progress in increasing the efficiency. The Admiralty had been doing a good deal in that direction in some of their fast, light-draught ships, and they obtained an increase of structural efficiency by the use of steel of higher tensile strength, without adding to weight of structure or draught of water. If that principle could be introduced generally into the mercantile marine, and if the Board of Trade and the classification societies would admit steel of higher tensile strength in important parts of the hull-structure and boilers—provided, of course, due precautions were taken to ensure proper ductility by testing the percentage

of elongation—it would be a help in many ways in improving the efficiency of ships and enabling British manufacturers to compete with shipbuilders who were running them very hard in foreign countries. In regard to steel for boiler-shells, he thought the highest tensile strength to which manufacturers had been allowed to go in this country was 34 tons per square inch; but steel plates had been made at home for the boilers of foreign ships having a maximum tensile strength of up to 38 tons per square inch. Unless British manufacturers were allowed to use material of the same efficiency as was used elsewhere for ships built in competition with them, they were of course handicapped by the difference in tensile strength, and all that this involved in modifying the details of design of hull and boilers. He hoped, therefore, that the Paper and the discussion on it would help to bring about an early assimilation of practice with regard to testing steel for ships and marine boilers, and would lead the officials of the Board of Trade and of the classification societies to see their way to enable builders to use steel of higher tensile strength than was now permitted. Dr. Elgar.

Dr. R. T. GLAZEBROOK ventured to make one remark, which might seem rash, in that it was contrary to the opinion that mechanical tests ought to be sufficient for the purposes of the engineer, which was expressed in the Paper and had been concurred in by the President. After considering some of the points that had arisen, he thought other tests beside mechanical tests might help to solve completely some of the difficulties that arose in the Paper itself. For instance, considering the question of the different tensile strengths observed in thin plates and in thick plates, referred to by Dr. Kennedy, it seemed to him that comparative microscopic examination of the section of that thick plate, and of the section of the thin plate, would probably yield considerable help in the solution of the problem [1]; for it was quite possible that, owing to the effects of chilling in the process of rolling, the structure of the thick plate was by no means homogeneous throughout; whereas in thin plates it seemed possible that homogeneity might have been secured throughout by the rolling and the subsequent cooling. If that were so, it seemed quite possible, bearing in mind the considerable differences in structure that resulted from cooling from certain temperatures, that the steel in the thick plate was Dr. Glazebrook.

[1] A microscopic examination of these plates has since been made at the National Physical Laboratory, and the results have been communicated to the Institution. See *post*, p. 411.—SEC. INST. C.E.

Dr. Glazebrook. not quite homogeneous—a point which might be cleared up by microscopic examination of sections taken throughout the plate. He merely cited this as one instance of the manner in which he hoped that other than purely mechanical tests might be of value and assistance to the engineer in questions of that kind.

Mr. Skelton. Mr. H. J. SKELTON had read with some satisfaction the reference in the Paper to axial stresses. Some years ago he had had to investigate a case of rejection by a foreign Government of a large number of plates. At that time the method of preparing the test-piece for breaking was to drill holes in the ends and put pins through. In the case in question those holes had not been quite central; consequently a ripping stress had resulted, and in no instance had an axial stress been applied to the specimen. The whole of the plates had been unjustifiably rejected, and great injustice done to the manufacturer. He was glad to find that English engineers were now better advised as to the proper shape of test-pieces. One point which might be emphasized was that all the tests described in the Paper had been made on plates. It was not possible to obtain uniform results from tests on structural steel of other shapes. Every engineer had experienced the fact that a flat bar ½ inch thick, of a given width and given tensile breaking stress, gave a superior elongation to a similar flat bar cut from an angle- or tee-flange. He thought the nature of the work done in rolling had something to do with that. If the results brought out by the Paper were to be used generally among steel-manufacturers, he hoped it would be observed that elongation would vary according to the variation of shape of the structural steel which was used. As one who had often had to stand between manufacturers and engineers, and to consider the question of rejection upon the results of tensile tests, and also as one having some appreciation of the difficulties of the manufacturer, he ventured to hope that Dr. Glazebrook would never ask, in actual commercial practice, for the whole of a plate-mill to be kept standing, or even the product of plates to be kept in the mill, until the structure of a plate was examined microscopically. The difficulties of such a course were evident to every practical engineer. All steel was not homogeneous, and never would be homogeneous in the strict scientific sense, and this was due to its irregularity as a fluid mass, and to segregation on cooling. Every steel-maker and engineer now knew far more about steel, its defects and its difficulties, than had been known even 10 years ago; and therefore the suggestion that some modification might be made in the excessive amount of testing and the excessive precautions which had been taken during the early stages of steel-manufacture, was a

very good one. Engineers were quite sure of getting a far more reliable product than had been obtained in the past. Some years ago he had made a series of tests on "Best Yorkshire" iron, wherein he had found the regularities of elongation within certain limits to be more remarkable than anything contained in the Paper. He had not been able to establish a definite proportion of elongation in specimens of different acting lengths; but he had been able to secure practically the same elongation over and over again in a given length, from different parts of the same bar and from a series of bars in a parcel. Mr. Skelton.

Mr. W. H. Pretty thought that if the distance from both gauge-points to the point of fracture were definitely stated, so that both measurements could be used to check any error made by the manipulator of the testing-machine, the superintendent of the tests would be enabled to form his own opinion as to what the actual elongation on the gauge-length should be. That would be a wise addition to the test-sheets, as tests were often made by a man who knew nothing of the subject, but knew simply how to work the machine, and had to do it rapidly, in order to get through his work. With regard to limits for the tensile strength of mild steel, much could be said in favour of retaining a limit system in preference to specifying minimum strength. It was well known that test-bars taken side by side from, say, a bar 4 inches in diameter, frequently gave a difference in tensile strength of quite 4 tons per square inch; and, therefore, it was reasonable to suppose that the steel required under a specification would be such that, if it came within the specified limits of, say, 28 tons to 32 tons per square inch, it would meet the requirements of a manufacturer or a consulting engineer conversant with the usual variations found in tests of steel. With regard to tests of thin plates, he had had some tests to carry out a few years ago on steel tubes, which he supposed approximated fairly well to the case of thin steel plates. Some difficulty occurred in getting a tensile test from steel tubes about 1 inch in diameter, which he surmounted by cleaning both ends of the test specimen, tinning them, plugging with steel pieces, and shrinking on the outside at each end a copper tube; then securing the whole together by drilling holes and putting rivets through, and finally soldering. By that means he had obtained good tests of the tensile strength of the tubes, and the fractures had been very instructive. With reference to the formula used in the German State laboratories, he had arrived at the formula $l = k\frac{A}{s}$, Mr. Pretty.

Mr. Pretty. where l was the gauge-length, A the sectional area of the test-piece, s the perimeter of the section, and k a constant. He had not yet been able to verify it with a large number of tests on various forms of section. With regard to chemical analysis of steel, when a student under the late Sir William Roberts-Austen, he had been much impressed by the importance attached by Sir William to the effect of the addition of minute quantities of an element to metals or alloys. Every day greater need was shown for attention to this matter. Regular testing was as important to-day as it had been 20 years ago. If the steel-maker was restricted to a given chemical analysis, there was not the slightest doubt that he would produce the steel required, with the strength and the elongation in accordance therewith. But all the energy and skill of the steel-maker was useless if the steel was not properly treated in the smithy. Thousands of forgings were spoilt in the smith's shop, and often an attempt made to damage the steel-maker's reputation. The mechanical engineer should study the chemical composition of steel and the effects of his operations upon such composition. So far as the chemical analysis of mild steel was concerned, a certain fixed state had been approximately arrived at, and it was possible that the presence of small quantities of elements not usually asked for, or even considered, might play an important part in the molecular arrangement of the constituents and affect the mechanical properties of the material in a way not detected by the usual applied tests. The chemistry of high temperature conditions was yet in its infancy; it should receive serious attention in all metallurgical problems, and pass through the whole history of the material to the finished article. In dealing with a quality-figure for mild steel, a desirable state of things was approached, and here again much might be said in favour of limiting stresses as opposed to a minimum stress; but it seemed to him that the steels should first be classified, and their suitability for mechanical purposes be judged, by reference to qualities for which a series of recognized standards were used, and in which increments of stress and increments of strain were considered. The quality condition should also involve a relation between the elastic limit and the ultimate strength, say, the ratio $\frac{\text{elastic limit}}{\text{ultimate strength}}$, and in which provision was made for guarding against artificial elastic limits. Standard test-pieces were as essential to engineering progress as units of length, mass and time, and should be as accurately fixed and guarded against future unauthorized alteration; but the question arose—

was it the material or the bar of metal that was tested? For instance, it was surely better to subdivide a bar 4-inches in diameter into several test-pieces than to make a testing-machine powerful enough to break the complete section. He was inclined to think that a 15-ton to 20-ton testing-machine should be large enough for any tests of the material, of which a complete quality-test was required, although not necessarily large enough to break the bar. He would suggest that 0·25 square inch or some near equivalent in square millimetres, was a suitable standard sectional area for mild steel. The cost of the test-piece should be as low as possible; many of the forms in use for scientific research were quite prohibitive in the workshop, speaking of mild steel only. A cheap and good form of test-piece for general workshop adoption would be one in which the two ends of the test-piece, which formed the grip, were in the form of frustums of cones with their bases at the ends of the bar. Similarly, test-pieces for plates might be longitudinal sections of such a design of test-piece. Economical testing did not necessarily mean inefficient testing; indeed, experience went to show that when a large number of tests were to be made at a contractor's expense, careful economic testing was far more satisfactory and reliable, since tests were then willingly made, and repeated if necessary. It should always be borne in mind that the usual testing-machine test was a steady-load trial, and was totally unfitted for material subjected to oscillatory mechanical stresses of high periodicity. It was a well-known fact that rods subjected to such oscillatory stresses (longitudinal and transverse), and which had given way under them, showed that after fracture the material in the immediate neighbourhood of the fracture, generally gave steady-load tests equal to the original requirements of the specifications. The rate of elongation, as determined by the gear of a testing-machine when mechanically driven, apparently had no recognized standard value, and the Author's remarks should lead to fixed values being given to this for machines worked both mechanically and hydraulically. Mr. Pretty.

Mr. A. F. Yarrow remarked that, the President having expressed the view that the results of some impact-tests on nicked steel bars might be interesting, he had placed on the table a number of specimens tested in the course of experiments made with a view to determine the most suitable steel for connecting-rod bolts, and other bolts of that kind. It was well known that when the cap of a connecting-rod was fastened with two bolts, in fast-running engines, one of the bolts sometimes slacked back, thereby throw- Mr. Yarrow.

Mr. Yarrow. ing a severe stress on the remaining bolt; and probably accidents had at times occurred from such a cause. The strain on the bolt was somewhat similar to that on a nicked bar subjected to a transverse stress, every screw-thread being, as it were, a nick; it was not a direct tensile stress on the bar. For these experiments a number of steel bars, obtained from steel-makers at home and abroad, had been planed down at the same time, and in the same machine, to exactly the same size, namely, 4 inches long and ½ inch square, and a nick had been made in them ⅛ inch deep. The tests had been made by placing the bars on supports 3 inches apart and allowing a weight of 10 lbs. to drop upon them from a height of 18 inches. The results were surprising. The ordinary tensile tests did not indicate in the least the relative merits of the bars under this impact test. All the steel was of good quality, the ultimate tensile strength of the mild steel varying between 28 tons and 32 tons per square inch, with an elongation, in 2 inches, of 30 per cent. to 33 per cent. Among the best of the steels was some nickel steel which had a tensile strength of 44 tons per square inch and an elongation of 43 per cent.—a combination of a high degree of elongation with great strength. All the steel was such as would pass the Admiralty tests. With regard to the number of blows each bar had withstood before failure, one had stood seven blows, another seventeen, the next twelve, and then three, five, four, one, seven, six, eight, and sixty-four; which indicated that under such conditions the tests usually adopted threw little light on the subject. In the first set of tests the blows had been given on one side of the bar only; afterwards, turning the bar over and over, so as to have the nick first at the top and then at the bottom, had been found to be less trying to the material: but the steel that gave the best result with the blow always on one side also came out best when the blows were delivered first on one side and then on the other. The wide differences between what steel bars would stand when nicked—when, as he had pointed out, they were subjected to practically the same strain as one of a pair of connecting-rod bolts when the other bolt slacked back—and their strength determined under the ordinary tests, was interesting, and might lead to consideration being given to impact-tests of nicked bars as a guide to the design of mechanism subjected to severe shocks.

Mr. Wicksteed. Mr. J. H. WICKSTEED considered that the question raised in the Paper was one of vast practical importance, not merely an academic question; and he thought an instance he had in his mind would bring that home. Not long ago a large number of

experiments had been undertaken in order to find out whether it was better for a steel plate to have much work or little work put upon it in rolling. With this object, some ingots 15 inches thick had been rolled down to ¼ inch, in order to carry the thing to an extreme, by putting a very large amount of work on the material; while other ingots only 6 inches thick had been rolled down to 1 inch thick. Ordinary tensile tests made on both plates had given 20 per cent. extension only for the ¼-inch plate and 25 per cent. extension for the 1-inch plate. He could not say whether the plates had been annealed; he thought they had been tested as they came from the rolls; but care had been taken that the small plates should not be rolled at too low a temperature, or be unequally cooled by local draughts. The curious feature of the matter was that the results he had mentioned had been taken as indicating, if not proving, that by rolling the plate down from 15 inches to ¼ inch, that was, to one-sixtieth of the original thickness, the plate had been made inferior in ductility to the one which had only been rolled down to one-sixth of the thickness of the ingot. If the Author's elongation-equation were applied to those plates, it would be found that there was a difference involved in testing a thin plate, if it was of the same length and width as a thick plate—a fact which had never once struck the experimenters, who were familiar enough with testing on ordinary lines. As nearly as he could make out, the application of the Author's elongation-equation to those plates would show them to have had about the same ductility; if anything, the ¼-inch plate would have been more ductile than the other. The faulty deduction from the tests in question had pointed to changes being made in the ingot-moulds and in the rolling-mills, and indeed in the whole policy of manufacture at the works to which he was alluding. This showed the importance of the matter; and he congratulated the Engineering Standards Committee on having been the means of bringing forth such an exposition of it as was contained in the Paper. It was not enough that such things should be known to scientists; as the Author remarked, they had been known to them since the time of the writings of Barba and Hackney. Yet specifications still went forth to the effect that the material was to show an elongation expressed as a percentage of the length between gauge-points, whereas in short pieces half of it was due not to the length, but to the sectional area. He was pleased to notice in Fig. 4, Plate 2, that the distance of the datum points from the enlarged ends was proportional to the length of the specimen. If, in geometrically similar specimens with Mr. Wicksteed.

Mr. Wicksteed. enlarged ends, the datum points were equally distant from the ends, comparable results would not be obtained. Either the extension must be taken from shoulder to shoulder, or the distance of the gauge-points from the shoulder must be proportional to the length of the test-piece. He thought that, instead of tabulating results which might be expected from standard bars of different lengths, or introducing an equation between direct measurements, it would be a great boon to those who wished to know the quality of materials, if the general elongation were separated from the local elongation. That was extremelv easy to do, because the general elongation went on just so long as the material could bear an increase in the load, and no longer. As soon as the piece finally yielded, and the steel-yard of the testing-lever dropped, elongation set in entirely at the weakest place in the bar, and the general elongation ceased. It was therefore only necessary to let the lever trip a pencil from a tablet, and cease marking the extension when it sank; the pencil then left behind it the full record of the general elongation. The total elongation could be measured in the ordinary way, by putting the two pieces together, and the difference was the local elongation. That was a simple operation, and did not require a stress-strain diagram, but merely observation of the point at which the general elongation ceased. Of course the testing had to be done more carefully and slowly, and it would greatly facilitate getting the exact point of maximum load if there were no inertia-stresses to contend with in the lever, which could be accomplished by limiting its range. A lever with a limited range had an indicator which showed when it was pressing against either the upper or the lower bar, and with what force. It was quite easy to adjust the poise so as to balance with the greatest exactness. When it was remembered that testing-machines were guaranteed by the makers to give a sensibility of 1 in 5,000 with a load of 100 tons, it could be understood that it was easy to define the point at which the general elongation ceased. Another advantage of separating the general and the local elongation was, that not only was the effect of all differences between samples in the matter of proportions eliminated in the general elongation—if the quality of the material was the same—but information was also gained as to how far certain materials would withstand reduction of area before actual fracture.

Mr. Robertson. Mr. Leslie S. Robertson gave an explanation of the object with which the Paper had been prepared. In the discussion which had occurred in connection with the drawing-up of a standard test-piece by the Engineering Standards Committee, certain limitations

on the test-piece proposed for plates had been asked for by practical men. The Americans and also the International Testing Association had adopted a length of 8 inches (200 millimetres). It had been suggested to the Committee that certain limits should be allowed in regard to the breadth, in the same way as a margin of 2 tons below and above was allowed to the makers in a specification for, say, 30-ton steel. The makers desired to have a similar allowance given to them on the breadth of the test-piece. Not being quite sure what that meant, the Committee had asked the Author to undertake the experiments which had formed the subject of the Paper. The Author had communicated the results to the Committee in a report published after the reading of the Paper, and in which he made certain suggestions as to the standard test-piece. The whole question would be discussed and settled at a general meeting to be held on the following day (18th November). The object of the experiments was to afford the Committee as complete information as possible on the point at issue. Mr. Robertson.

Mr. F. W. Dick mentioned that some weeks ago the Author had sent him the formula connecting local extension with general extension; and he had been so interested that he had immediately begun to have experiments made with a view to test it in practice. He had first made from a round bar a series of test-pieces in which the length and the diameter varied; he had endeavoured, in fact, to make the first term on the right-hand side of the equation constant. He had not recognized until after reading the Paper that he was merely making geometrically similar test-pieces, and therefore proving Barba's law. But a curious thing had happened in the course of the experiments. The calculated extension for the steel was about 31½ per cent. The observed extensions varied between 30 per cent. in the lowest and 32½ per cent. in the highest, the average being practically 31¼ per cent., except in the 8-inch piece, which, strangely enough, gave an extension of 40 per cent. In that test-piece, however, there were two reductions of area. According to the formula, the local extension should be 8·48 per cent., while the general extension was 22·72 per cent. But as there was a double reduction of area the local extension had to be reckoned twice, and $22 \cdot 72 + 2(8 \cdot 48) = 39 \cdot 68$, which was in very close agreement with the 40 per cent. actually obtained. He thought that showed in a remarkable way the correctness of the distribution of the two extensions in the Author's formula. He had prepared another series of bars, of uniform diameter and different lengths. He had soon found that the Mr. Dick.

Mr. Dick. formula was not applicable to the shorter lengths, a fact which the Author had mentioned in the Paper at p. 180, where it was stated that the formula did not apply when the value of $\sqrt{A} / l$ was less than $\frac{1}{4}$. He could not help feeling, from his experience as a steel-maker and from the anomalies he had met with in specifications, that the Paper was by far the most valuable communication on the testing of steel which had ever, to his knowledge, been published. He hoped it would be widely studied, and he expected important results from it. For instance, only the previous day he had been asked to quote for steel hoops—for what purpose he did not know—$\frac{7}{8}$ inch wide and of No. 19 gauge, with a tensile strength of 28 tons to 32 tons per square inch and 20 per cent. extension in 8 inches; and he had been obliged to reply that the conditions were impossible to fulfil. He desired to emphasize the fact—which the Author recognized clearly—that the constants in the formula depended on the nature of the test-piece. If the same quality of steel were rolled into round bars and into flat bars the constants would differ; if the material were rolled into thick plates the constants would again differ; and they would be different again for thin plates. The Author also pointed out that it was beginning to be recognized that the quality of steel depended as much upon its structure as upon its chemical composition. That was very true; and he could not help thinking how little known it was, and how little it was appreciated, when Mr. Wicksteed referred to the experiments of rolling a small ingot into a thick plate and a thick ingot into a thin plate. Such experiments were wholly erroneous and misleading unless the finishing conditions were known: the intermediate stages were not worth thinking about. With regard to steel castings, as the President was no doubt aware from his own experience, a steel casting which had not been rolled or worked in any way, but had simply been cast in the mould, could by heat-treatment be made to show the same extension, bending qualities and ductility, as a rolled plate or a hammered bar. It would be seen from the Tables that the Park Gate $\frac{1}{4}$-inch plate had a rather higher breaking stress, and gave much less extension, than its thicker fellows rolled from the same steel: that was simply because it had been rolled cold. Again, it would be found that the thicker plates had much less ductility; some of the broken test-pieces had a brittle appearance: that was because they had been finished at too great a heat. All those things had to be taken into account; and the toughness of the steel was really dependent on its final condition. Although there was a difficulty in getting 20 per cent. extension in $\frac{1}{4}$-inch plates,

Mr. 1.

manufacturers were frequently called upon, especially by torpedo-boat builders, to give 20 per cent. extension in a plate only $\frac{1}{8}$ inch thick. They did it by after-treatment, namely annealing or toughening the steel after rolling. He wished the difference between toughening and softening were more clearly defined, and that the two things were not put under the one head of annealing, which he felt sure caused confusion. Specifications often said that after the steel was rolled it was to be covered with ashes and allowed to cool slowly. Could any one conceive of a better way of producing large crystals? Slow cooling was known to produce large crystals. If the steel happened to be below the proper finishing-point before it was put in ashes, no harm was done; but if it was finished at a high temperature and then put in ashes the material would be brittle. Formerly, if in working tool-steel it was found that it could not be turned, it was taken to the smith, who heated it up and put it in lime, and then it was found that the steel could be filed and turned easily. But the steel had not thereby been toughened; it had been softened. It was re-hardened by being brought again to a temperature high enough to restore the original chemical condition, and quenched quickly. In annealing steel plates the object was to have a fine crystalline structure, and to bring the steel to its original toughness. That was why a steelmaker did not like to guarantee more than 20 per cent. elongation in 8 inches. Differences in shape—the round shape was the most favourable—differences in thickness, and in the temperature at which the material was finished, all caused differences in ductility. It also explained why an engineer who was content to specify a minimum elongation of 20 per cent. in 8 inches found that he frequently obtained much more than that figure—from 22 per cent. up to 30 per cent. and even more. All mild steel could be brought to the same condition by annealing; the question for engineers to decide was, was it worth while going to the expense of obtaining the higher elongation? Personally he did not think it was. For instance, in structures engineers did not always use an expensive material, such as steel; they used cast iron and wrought iron in certain places. An extension of 20 per cent., and a bend that doubled up, surely showed ductility enough to cover any distortion that might come on an engineering structure short of destruction. Mr. Dick.

Captain H. RIALL SANKEY observed that on p. 200 the Author proposed that the value of l/d should be equal to $3 \cdot 54$, and said: "Probably, however, objection would be raised to this in ordinary commercial testing." It might interest the Author to know that Captain Sankey.

Captain Sankey. that ratio had been adopted for the past 2½ years in the works of Messrs. Willans and Robinson, at Rugby, where a set of curves somewhat similar to those shown in Figs. 9 and 10, had also been in use, for reducing the elongation of any particular specimen to the standard size. Mr. E. G. Izod, who looked after the testing at the Rugby works, was responsible for the arrangement.[1] In regard to the Author's remarks on the quality-figure (p. 202), at first sight it might be thought that the value of steel could thus be told at a glance; but, as the Author carefully pointed out, it was only possible to use a quality-figure, when the same class of steel was being dealt with: in other words, various classes of steel must be put into water-tight compartments as it were. He thought there was a danger in that method, because figures had the faculty of surrounding themselves with a halo of exactitude, and engineers who did not quite follow the reasoning, or who forgot the limitations, might later on use the quality-figures in a way in which they were never intended to be used. The Paper gave two examples which brought out that point, and the accompanying Table contained three more. The first example in the Table was

Specimen No.	Yield-Stress.	Ultimate Stress.	Elongation in 2 Inches.	Quality-Figure. $f + e$	Brittleness $\frac{1}{f \times e}$	Resistance to Shock.
	Tons per Square Inch.	Tons per Square Inch.	Per Cent.			
174	38·0	49·3	23·0	72 3	..	..
5,057	15·0	22·2	48·5	70·7	..	..
1,109D (Hadfield)	18·0	50·0	75·0	125 0	..	..
						Foot-Lbs. on Standard.
5,192 Flat plate	37·0	52·0	25·0	77·0	0·077	19·0
94	23·5	42·1	26·0	68·1	0·091	3·8
4,824	14·5	25·4	40·0	65·4	0·100	2·8
5,057	15·0	22·2	48·5	70·7	0·093	18·0

a steel whose ultimate tensile resistance was 49 tons per square inch, with an elongation of 23 per cent., giving a (modified Wöhler) quality-figure of 72·3. The second example gave 22·2 tons per square inch ultimate strength, 48·5 per cent. elongation, and a quality-figure of 70·7. Those two steels were not of the same

[1] See Mr. Izod's remarks in the Correspondence, p. 277.—Sec. Inst. C.E.

class, and it would never do to compare them by these quality-figures. The first example (Specimen No. 174) compared somewhat with one given in the Paper, a 44-ton steel with 10 per cent. elongation, which had a quality-figure of only 54; yet it could not be said that the values of those two steels were in the ratio of 54:72; they were quite different materials. He wished also to refer to a steel which Mr. Hadfield had called attention to at the last Engineering Conference of the Institution.[1] Mr. Hadfield had represented it as a very peculiar material. It had 50 tons per square inch ultimate tensile resistance, and 75 per cent. elongation on a 2-inch specimen, giving a quality figure of 125. The ultimate strength was very nearly the same as in Specimen No. 174 in the Table (p. 252), but the quality-figure in one was 72 and in the other 125, and it might be thought that the one steel was almost twice as good as the other. But the yield-stress in the one case was 38 tons, and in the other only 18 tons, per square inch; so that in reality the first steel was far better for engineering purposes than the second. He hardly agreed with the Author in giving the yield-stress such an unimportant position. On p. 203 it was stated: "For certain purposes no doubt it is important to specify the limit of elasticity, or the yield-stress as well as the breaking stress." He could not help thinking that the yield-stress was by far the more important. In the above examples if a factor of safety of 4 were taken on 50 tons, the result would be 12½ tons. In the one case that would be nearly up to the yield-point, while in the other there would still be a factor of safety of 3. On p. 173 the Author said: "Recently, notched-bar tests, either by statical loads or by impact, have sometimes been described as tests of ductility." He thought it would be more correct to describe them as tests of resistance to shock. The remarks he had intended to make on this subject had been largely anticipated by Mr. Yarrow. There were four examples in the lower portion of the Table (p. 252), which confirmed exactly what Mr. Yarrow had said. The first was a 52-ton steel, with 25 per cent. elongation, which gave a brittleness of 0·077, as defined by the Author at p. 173. The brittleness was really Tetmajer's quality-figure. That specimen required 19 foot-lbs. to break it. The second steel, of 42-tons per square inch ultimate strength, gave 26 per cent. elongation, with very nearly the same brittleness, and required Captain Sankey.

[1] "Alloys of Iron, Manganese and Nickel." Minutes of Proceedings Inst. C.E. Supplement to vol. cliv. p. 118.

Captain Sankey. only 3·8 foot-lbs. The other two examples in the table were a 25-ton steel showing 2·8 foot-lbs., and a 22-ton steel showing 18 foot-lbs.; so that in no instance did the resistance to shock correspond either with the ultimate stress or with the elongation: nor did it agree with the quality-figure arrived at by adding the breaking stress and the elongation, or with the "brittleness" obtained by taking the reciprocal of their product. He thought one of the main lessons to be learned from the Paper was the great care that had to be taken in making tensile tests; so much so, that it seemed hopeless to carry them out in a workshop; they must be carried out by experts in a well-equipped laboratory. On that point the Author's remark that in Germany most of the tests were made in State laboratories was very significant. No doubt tensile tests properly carried out were needed for large contracts; but in engineering workshops some sort of testing for materials had to be done every day, and it would be impossible, for want of time, to send the test-pieces to a laboratory to be tested. Some workshop-tests were therefore needed which were something better than the ordinary "turn your piece of iron round a diameter and beat it down." It seemed to him that the resistance-to-shock test promised better than anything else in that direction, combined with a simple shear-test. He was working at that subject at the present moment with his assistant, Mr. Izod, and they had great hopes of being able to evolve some simple workshop-tests. If they succeeded, he hoped to present the results to the Institution.

Mr. Firth. Mr. BERNARD A. FIRTH wished to speak in the interests of manufacturers, as opposed to the technical opinions which had hitherto been put forward. The subject of testing was one of the most important branches of manufacturers' work; in fact, it had become so important that they were keenly interested in the experiments carried out by the Author. They felt that the testing should, if possible, be carried out in the testing-room; and that had brought about a proposal for an alteration in the bend-tests, which were the customary tests of the present day. The bend-test was generally taken on a 1-inch square bar. Few manufacturers possessed testing-machines on which they could bend properly a test-bar 1 inch square, consequently the general custom was to take the bars to the smithy. That seemed to be an altogether wrong system for the bending-test, and he hoped the investigations of the Engineering Standards Committee would find a means of getting over the difficulty. Probably the best plan would be to use a smaller bar. From the manufacturers' point

of view, the present bend-test was very extravagant. As a rule, consulting and inspecting engineers had their own ideas as to the size of the test-piece. In ordinary forgings, most tensile tests could be obtained from a 5-inch length, but a 10-inch test-piece had to be taken in order to get the bend. If a manufacturer was making fifty axles or other forgings, and the inspector did not appear until they were made, every one of those forgings had to be left with a piece large enough for making a bend-test when the inspector arrived: which meant that every forging must have left at the end an additional 10-inch length, of whatever diameter the forging might be. Manufacturers hoped that the Standards Committee and consulting and inspecting engineers would help them to avoid this serious waste. To some, 10 inches of steel might not seem to be a great waste, but when it occurred on every forging made, it came to a very large quantity of material per annum. He felt strongly that a proper bend-test was not obtained. The plan of taking a bar to the smithy and bending it round a round bar, and then closing it under the hammer, was not a bend-test. What he had been working for, and what he hoped would eventually come about, was that bend-tests should be pressed through a die. Tests were as important for guns as for anything else, and the War Office were satisfied to take a bend-test on pieces $\frac{3}{8}$ inch by $\frac{3}{8}$ inch in size: he hoped the same test might be applied to all other forgings. The Author mentioned that it was difficult to make comparisons with the present methods of testing, and that was a strong reason why engineers should try to arrive at a standard size. Every day engineers were asking for the same results with all shapes and sizes of test-pieces, and the manufacturer never quite knew what he had to do. One day he was asked to obtain certain results with a 2-inch test-piece, and the next day he was asked to obtain the same results with an 8-inch test-piece; whereas there was no doubt that a different material had to be used in order to obtain the same result with a test-piece of different size. He thought that point was not fully realized by a great many people who drew up specifications, but he believed manufacturers would agree as to its truth. Mr. Firth.

Mr. F. E. Robertson thought the Paper was so good and dealt with the subject so thoroughly that it left little to discuss beyond the application in practice of the data the Author had given. Many engineers recognized, although it was surprising how many did not, as corroborated by Mr. Wicksteed, the essential relation of area to length in regard to elongation; but it was only now that, Mr. Robertson.

Mr. Robertson. thanks to the Author, they were in possession of the data which would enable them to connect the results from differently shaped test-pieces. There was, however, one question he wished to raise. Taking the Tables beginning on p. 192, which compared the observed and the calculated elongation, the Author said, "The calculated elongations are deduced from the values of the constants given above." He had tried two or three of the constants, and could not reconcile them. The expression was ambiguous, because the mean values of all were given, and the mean values of the Motherwell plates, and of the Park Gate plates, could also be taken. He would be glad if the Author would state which the particular constants were that had been used in calculating the elongations. Two or three years ago he had altered the traditional length to a minimum length of nine times the square root of the area, in his specifications. There had then ensued a a great outcry; everybody had said they would never get the testing done. But he had pointed out that they were not asked to do anything different from what they were doing every day, except in the case of very thick plates, which did not often happen; and since then the testing had been going on satisfactorily. Anybody who had had to do with testing in a rolling-mill would recognize the absolute necessity of getting through the tests quickly, and the impossibility of ensuring scientific accuracy. The Author and one or two speakers had questioned the utility of maximum tensile strength and of chemical analyses. With regard to maximum tensile strength, if a minimum strength and a minimum elongation were specified, a maximum was virtually specified; perhaps it was scarcely necessary to put it in the specification, because it settled itself. In regard to chemical analysis, he would only say that in the present state of the art of steelmaking, some assurance was required that the steelmaking was going on regularly; and although of course analysis would not tell the engineer everything, since a bad steel might show a good analysis, there was no doubt it was a valuable aid towards obtaining uniformity of product. At least, he thought it might be left in specifications. His practice was not to analyze structural acid steel as a rule; it was sometimes analyzed to see how things were progressing. Basic steel, however, was usually analyzed, because he thought it was hardly so regular a product.

Mr. Wentworth-Sheilds. Mr. F. E. Wentworth-Sheilds considered that the Paper showed how unsatisfactory were the present Admiralty and Lloyd's tests for mild steel. For instance, on p. 208 results were given for a set of

plates which the Author said were ordinary plates, and in no way specially selected. In ductility one of those plates fell considerably below the average. As it happened, the test-piece was large, having an area of about $1\frac{1}{4}$ square inch, and gave an elongation of about $22\frac{1}{2}$ per cent. The Author's formula would show that were that test-piece reduced to something like $\frac{1}{2}$ inch by $\frac{1}{2}$ inch, its elongation would fall to 19·4 per cent., and therefore fail to pass the 20 per cent. limit, although the material was the same. From the Paper one or two suggestions for a remedy might be gathered, although the Author did not insist on or strongly recommend any of them. The standard bar—a bar of standard length and standard area—had been referred to, but that would give the makers a great deal of trouble, and would be open to objection accordingly. Another suggestion which might be open to far less objection was to have the gauge-length altered to suit the size of the bar; that was, to make it equal to the square root of the area multiplied by some constant. That would be troublesome, but not so troublesome as the first suggestion. The third suggestion was found in the Paper, namely, that if instead of measuring only the extension in 8 inches it were measured on two different lengths, say 8 inches and 4 inches, it would be possible, by a simultaneous equation, to arrive at once at the value of the constants in the formula given. That could be done quite easily, but it involved somewhat intricate and laborious work. A fourth suggestion occurred to him as being a little simpler. Ductile steel was required—at all events in structural work—because, owing to imperfections of workmanship, it might happen that one particular piece was taking more than its proper share of the stress. For instance, if there were six rivets in a joint, it might happen that, owing to imperfect workmanship, one rivet for the moment was doing all the work. That rivet was wanted to yield slightly, and thus allow the other five rivets to come into play. In so doing, the rivet was not destroyed; it was merely strained to something like its yield-point, or perhaps a little bit beyond. Consequently, steel was required which would stretch as much as possible for a given stress, not at the breaking point, but at, say, the yield-point, or something a little above it. In short, the constant b in the Paper was required to be as high as possible, and it did not matter at all in structural steelwork how high or how low the constant c was. That being so, would it not be possible to make the observation in such a way as to eliminate entirely stretching at the breaking point, by choosing the gauge-points not in the ordinary way, one on each

Mr. Wentworth-Sheilds.

Mr. Went-worth-Sheilds. side of the fracture, but both on one side of the fracture? In order to do that, of course, many gauge-points would have to be marked. Instead of marking two gauge-points 8 inches apart, it would be necessary to mark seventeen gauge-points ½ inch apart. After the specimen had been broken, the longer portion would be taken, and two of the gauge-points selected as far apart as possible—subject to the condition that they were free from the influence of the local elongation due to the fracture, and, of course, of the lack of elongation at the fixed end of the bar—and the extension which had taken place between them would be measured. It might be objected that, with this method, a longer specimen would be required than the ordinary 18-inch bar now in use; but p. 210 of the Paper showed that if the gauge-point nearest the point of fracture was not nearer to it than about 1½ inch or 2 inches, it would be free from the influence of the local elongation at the fracture. How far it would be necessary to take the other point from the end of the bar, he would not like to say; probably further experiment would be necessary to decide that question. The Author did not state, in the Table on p. 209, how near to the end the measurements were taken, and it would be interesting if that information were added. But it seemed likely that at least a length of 2 inches could be taken at one side of the bar, even in the worst case, namely, where the bar broke exactly in the middle; and it would be quite easy to measure the elongation on 2 inches within 1 per cent., without any special apparatus. That method, it seemed to him, would give a measurement of elongation which would be independent, not only of the area, but also of the length between the gauge-points. No special formula or calculation, other than the simple calculation now in use, would be required; no special apparatus would be wanted, or special bar; and last, but not least, it would tell the tester exactly what he wanted to know.

Mr. Kirkaldy. Mr. W. G. KIRKALDY was glad to see that the Author had touched upon the question of specifying an upper limit for tensile strength as well as a lower. He had personally contended for many years against the insertion of an upper limit, as being unnecessary; because the stipulation that the contraction of area, or, if preferred, the extension, should not fall below a certain amount, prevented a manufacturer from getting a brittle or undesirable material passed. He considered that restriction of the quality within hard-and-fast limits, not only hampered the manufacturer unduly, but tended to retard or prevent improvement in quality. He had for long been hoping to see a higher grade of steel come into use, but it had doubtless been delayed by such

Mr. Kirkaldy.

specifications. Similarly, he did not think it well for the engineer to dictate a rigid formula for the chemical composition; it was better to have more carefully defined and rigorous physical tests to ensure the finished article or material being suitable for its purpose, while allowing the manufacturer as full scope as possible for arriving at a good result in his own way; thereby stimulating, instead of restricting, improvements in manufacture. He had been glad to see in recent years that more attention was being given to the proper heat-treatment of steel, a matter which he considered to be of great importance. In many cases, he believed, heat-treatment had more effect upon the physical qualities and value of steel than its chemical composition. He had always taken great care to maintain a uniform rate of testing in the various classes of tests, and had paid the closest attention to accuracy of finish in test-specimens, in order to ensure true parallelism and uniformity in section along the length. His practice also was to measure for thickness at three points of the length on each edge, and, where necessary, also at three positions along the centre line of the specimen. His father, the late Mr. David Kirkaldy, had striven ardently at the commencement of his testing-operations to inaugurate and maintain standards in all his work, and had thereafter adhered rigorously to those standard sizes for each class of specimen or material; and it had been a cause of much regret to see many sizes and shapes gradually introduced by makers and others who had occasion to carry out tests, until it seemed practically hopeless to adhere to any one standard, in spite of the desirability of doing so. It might be well to put on record that Mr. David Kirkaldy had arrived at a figure of merit by dividing the breaking stress by the contracted area at fracture, and much could be said in favour of that method; to mention one point only, the result was not affected by differences due to either the length or the section of a specimen. He had a strong affection for the contraction of area, though he admitted the trouble of measuring it. But when the contraction of area was measured—and he was doing this every day without finding any special difficulty about it—something was obtained which was unaffected by length or by sectional area; and he found it was a very useful criterion. He measured the extension also; but he always leant towards the contraction of area. If that were satisfactory he would recommend the acceptance of the steel, although the extension might be low. With thin sections it was difficult to get a good apparent elongation. The material might be good, and the toughness satisfactory;

Mr. Kirkaldy. yet if the section was small and of a fair length, down went the elongation: but if the latter was taken in conjunction with the contraction he considered that the real ductility was brought out. It would probably mean a great deal of work, but personally he would be greatly obliged to the Author if he could interpolate the contraction in his Tables. Although the elongation varied according to the length of the test-bar, the contraction was constant—a fact which would then come out clearly in the Tables. The custom his father had adopted, and which had been maintained for 35 to 40 years, was to aim at a longer length than necessary, so as to avoid the influence of the enlarged ends. He had always subdivided specimens into divisions, on the same principle as the Germans, but not to the same narrow or extreme degree. He then took the best extension for a given length, usually with the fracture at the middle of that length, but not necessarily so, because occasionally the best extension was obtained with the fracture to one side of the middle of the length. It had been his invariable custom to take the extension on two gauge-lengths, and a great many tests on three or four lengths, so that any difference due to section could then be taken into account.

The President. The PRESIDENT enquired whether Mr. Kirkaldy generally took 8 inches as the length.

Mr. Kirkaldy. Mr. KIRKALDY replied that he used both, 8 inches where specified, but otherwise 10 inches, which he greatly preferred. He was sorry that the Standards Committee had chosen 8 inches, although, of course, there was something to be said for it. He need not enlarge upon the merits of the 10-inch standard now so well established. He had always used a standard width of 2 inches, and allowed the section to vary according to the thickness of the material, for practical reasons. It was a pity to machine down a 1¼-inch plate to a thin section, and thus get a standard specimen at the cost of losing the chief information desired for practical purposes, namely, how the material had been worked, and whether it had been properly rolled. The structure in the centre of a thick section of plate badly worked might be very poor. While the outer portions might be excellent, the centre might be unworked. It was not necessary to make a microscopical examination in order to ascertain that, for it was so pronounced that it could be seen with the naked eye. He wished there was a word which would convey that appearance and which could be put in the "remarks" column of a test-sheet. He believed the Germans had a word for it which conveyed the meaning very clearly. Personally he used the term "unworked appearance,"

but it was a roundabout and unsatisfactory expression. With reference to steel castings, it was possible with good castings of suitable quality, properly dealt with in respect of heat-treatment, to obtain a steel, the behaviour of which as to tensile strength, extension, contraction of area, and appearance of fracture, was practically like wrought or worked steel. He had had experience of many steel castings which, had he not personally seen the original skin upon the samples before they were machined for testing, he would not have believed to be in the cast state. The following results were mean figures obtained from 130 tests out of one series of 500 tests, and might therefore be of practical interest. All the samples had been cut off actual steel castings being supplied for a marine contract and had not been specially cast as test-bars. Mr. Kirkaldy.

Sectional Area.	Tensile Strength.	Contraction of Area at Fracture.	Extension in 5 Inches.
Square Inch.	Tons per Square Inch.	Per Cent.	Per Cent.
0·3	28·7	51·7	27·3

Mr. J. C. Inglis was very glad to notice that two speakers had referred to impact or shock tests. He spoke in the interests of rails. He had had to do with many kinds of tests, and he and many others thought the shock test was of great value. He was pleased to hear from Mr. Yarrow and Captain Sankey that the character of such tests was being closely examined. He thought all that had been said about the complication of the relations between the test-length and the area was of great value, but it did not cover impact questions, with which railway engineers were intimately and vitally concerned. Mr. Inglis.

Mr. R. H. Read thought the fact that test-pieces sometimes broke beyond the gauge-point and near the enlarged ends might possibly be accounted for by the way in which the test-pieces had been sheared from the plates. He was an old inspector for Sir Benjamin Baker and Sir Alexander Rendel, and vast quantities of test-pieces had passed through his hands; and he had noticed in the steelworks how samples for tensile tests and bend-tests were taken from the shearings of the sides and ends of the plates—the dregs of the material. Just on the edge of the plate there was a lateral flow of the metal in rolling, as well as a forward flow, and any little irregularities and defects in the ingot generally found their way to the edges of the plate. It was quite possible that some unobserved laminations or defects might occasionally occrr in those portions along the edge from which the test samples were selected, and might cause them to break unaccountably. It was Mr. Read.

Mr. Read. for that reason that a $\frac{1}{2}$-inch bar would give a better result on being tested than a $\frac{1}{2}$-inch plate. Engineers might rest satisfied that if the samples of a plate, as usually selected, stood their specified tests, the bulk of the plate itself would give still more satisfactory results.

The Author. The AUTHOR, in reply, expressed his thanks for the exceedingly kind way in which his Paper had been received. He had hoped that it would give rise to more criticism: there was hardly any one point upon which his conclusions had been absolutely dissented from. To the Author's great regret, Mr. Denny, the Chairman of the Sub-Committee for which the tests had been made, was unable to be present. When the Committee started its work, Mr. Denny put forward the view that if any standard system of specification and testing was to be adopted, there must be some rational basis for the work; and it had been very largely due to the encouragement the Author had felt, from the attitude taken by Mr. Denny, that he had ventured to push to the conclusions stated in the Paper, ideas and observations which he had made many years earlier. He believed there was really nothing that was quite new in the Paper, but on many points on which there was only vague knowledge and vague impressions he had tried to reach measurable quantitative conclusions. If the Paper had any value at all, it lay in the tabular matter, which showed how far the conclusions he had come to were justified by a series of tests on widely different materials. He would like to say something about the different attitudes of mind in England and in Germany towards the whole question of testing. In the first place, in Germany there was the International Testing Association, on which were represented the chief scientific engineers in Germany, Switzerland, Austria and Russia, and on which, unfortunately, there was little English representation. It included also the chief manufacturers in those countries, and met once a year for a session of a week, in order to discuss methods of testing. There were in Germany, Austria and Switzerland State Laboratories equipped in a way with which no English laboratory could compare, among the chief being those of Berlin, Zürich, Munich and Vienna; and quite recently the French Government had been establishing a French laboratory for testing, on a scale very much larger than anything in England. The largest of the German laboratories was that at Charlottenburg; and after some experience of the work of the "Versuchsanstalt" at Charlottenburg, the Germans had come to the conclusion that it was not big enough, and were moving the whole of their machines to Gross Lichterfelde,

where there was more space available than at Charlottenburg, and where a 2,000-ton testing-machine was being built, capable not only of applying a force of 2,000 tons, but also of taking in large parts of structures. He did not say that the Germans were right, or that English methods were right; but he did wish to emphasize the fact that a very different attitude of mind on the whole question of testing prevailed abroad. The Paper was limited to commercial testing, or such tests as might be included in specifications; he could have said much more if he had gone into the refinements of laboratory work, but he wished to limit himself to conditions which might be taken note of, and which he thought should be taken note of to some extent, in ordinary commercial testing. As to the question raised by Dr. Kennedy, whether the plate or the test should be rejected when fracture occurred by a tear from one edge of the plate, it was clear that such a result would be produced, and probably generally was produced, by non-axiality of the tension, that was, by imperfect gripping. It seemed therefore to the Author that the test must be rejected, though the plate might be accepted at the discretion of the engineer. In such cases the local contraction was imperfectly developed; and though the strength might not be greatly affected, the elongation was markedly reduced. Table 4, p. 182, contained an answer to Dr. Kennedy's question as to the extent to which form of section affected the elongation. The results in the Table on p. 186, to which Dr. Kennedy referred, were the mean results of all the tests of Motherwell and Park Gate plates. The test-bars were of the ordinary kind, but were longer than usual. The results were plotted in such curves as those shown in Fig. 6, Plate 1. From the curves the elongations for bars in which $l / \sqrt{A} = 8$ and $l \sqrt{A} = 11 \cdot 3$ were measured, and the means of these results were given in the Tables on p. 186. Dr. Glazebrook was no doubt absolutely right in the suggestion that microscopical examination would probably throw light on the cause of the different ductility of thick and thin plates. But that was a matter rather outside the scope of the Paper. It would not be possible to include microscopic examination among ordinary specification tests. Mr. Pretty's suggestion that the distance from fracture to the nearest gauge-point should be noted on test-sheets was useful, but perhaps it did not go far enough. The Author would prefer that if the fracture was outside the middle half, or, at all events, the middle two-thirds of the gauge-length, the elongation should be rejected as untrustworthy, or, at least, not be held to disqualify the plate. He doubted if in two test-bars, cut side by side, the tenacity The Author.

The Author. would differ by 4 tons per square inch. If that occurred he would suspect fault in testing. Mr. Yarrow's notched-bar tests were very interesting. The Author had obtained very similar results. He thought that it was better to break the notched bar by a single blow, and to measure the residual energy of the striking body. The whole subject of the behaviour of materials in impact tests certainly required further investigation. He did not quite understand Mr. Wicksteed's suggested method of determining the general elongation. If a load-strain diagram was taken, it was easy to measure the general elongation if the lever was kept floating near the point of maximum load. But it was not desirable that a load-strain diagram should be required in ordinary testing. On the other hand, it would not do to trust an ordinary testing-machine observer to note the maximum load by the lever-drop. When the lever dropped, the local extension had already begun. It was extremely satisfactory to him that so experienced a steel-manufacturer as Mr. Dick had found the Paper useful. Captain Sankey's Table was very interesting. It might be said at once that there were some materials which apparently had no real elastic limit, but which would extend enormously before fracture, and which therefore gave a very high quality-factor. But these were abnormal materials. Such results were not obtained with steel of commerce, and he did not think that results obtained with them could be used to discredit the quality-factor, used with reasonable regard to the conditions in which it was applicable. Such abnormal materials were really very ductile, and if they were not used, it was because of some other defect. Captain Sankey thought the Author had given the yield-stress too unimportant a position in testing. He had not said much about it, because he believed the ordinary methods of observing the yield-point to be highly unsatisfactory. If the yield-point was determined by observing the first visible stretch with compasses, the method was very rough, but not altogether untrustworthy. The more ordinary plan of noting the yield-point by "lever-drop" might easily be quite fallacious. With regard to Captain Sankey's suggestion that tests on notched bars should be called shock tests, in the Author's opinion it was not certain that the mode of straining the bar by impact had much to do with the results. Similar results were obtained when notched bars were broken by a steady load. The notch determined a *progressive* tear, and it was the mode of fracture which mainly influenced the results. He considered Mr. Firth's remarks about bend-tests to be important, and believed that speaker was entirely

right as to the proper method of making bend-tests. In no direction was some attempt at standardizing more desirable than in such workshop-tests as bend-tests. Mr. F. E. Robertson had no doubt discovered that in the Tables, pp. 192–194, the calculated results were obtained from the constants for each bar.[1] The first object had been to find whether the elongation-formula would fit a series of observations at different gauge-lengths on one bar: afterwards had come the question of how the constants varied for different bars. Mr. Wentworth-Sheilds's suggestion for measuring the general elongation was ingenious; but it would be desirable to have some experimental evidence of how it would work in ordinary testing. Mr. Kirkaldy naturally and rightly expressed his preference for contraction of area in place of elongation; but in addition to what was said in the Paper, it might be pointed out that contraction of area was mainly a measure of local contraction, whereas elongation depended on both general and local extension; and there were some reasons for thinking that general elongation was important as a measure of ductility. The Author.

The PRESIDENT remarked that, although the members at the commencement of the discussion had passed a vote of thanks to the Author for his very valuable Paper, each speaker had thought it well to add his personal thanks, thereby emphasizing the indebtedness of the Institution, but also occupying time that might have been better spent in discussing the Paper. He did not propose to say anything at that late hour, except that he thought the test-results relating to ¼-inch plates indicated that it was desirable, or rather necessary, that the makers of those plates should furnish particulars as to the ingots from which they had been produced, and in what condition the plates had been left, especially whether they had been annealed after rolling. Mr. Dick had darkly hinted that treatment might have a marked effect on the quality of steel—a fact every one was familiar with, and on which, he felt sure, a great deal more was bound to be heard. He was one of those who thought that heat-treatment would take the place of mechanical work to a large extent in the future. It was necessary to know the nature of the ingots, and what amount of mechanical work had been done on the material in manufacture. Without making any reflection on the maker, he was of opinion that some details as to the crystalline structure of the fracture—not its microscopic crystalline structure, but what could be observed with the naked eye—would be of great value. The President.

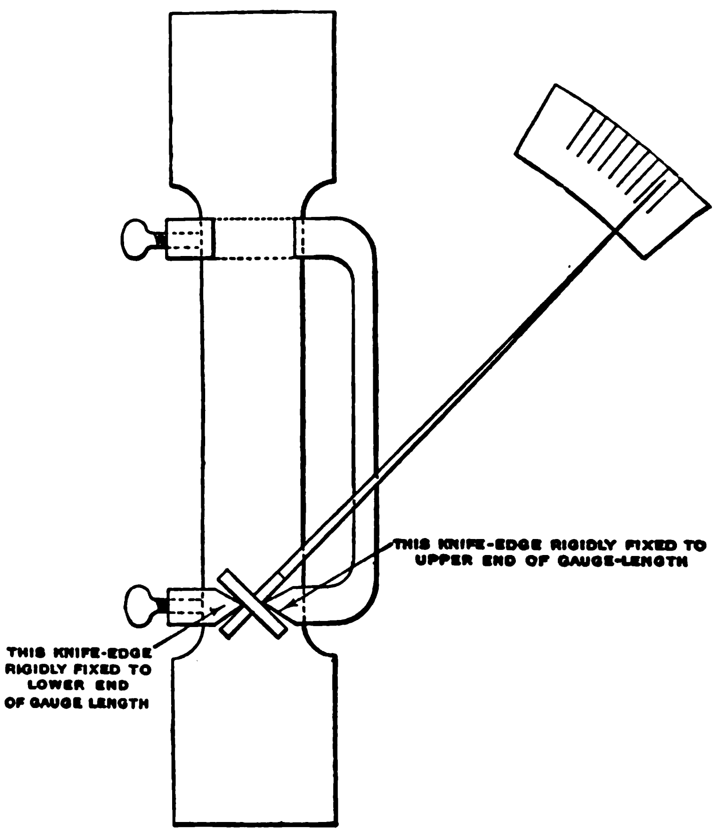
[1] There were three errors of transcription in the Table on p. 191 as first printed. —W. C. U.

[CORRESPONDENCE.

Correspondence.

Mr. Ashcroft. Mr. Andrew G. Ashcroft contributed a description of two of the instruments exhibited at the meeting, known as single-lever extensometers, which had been designed in the engineering

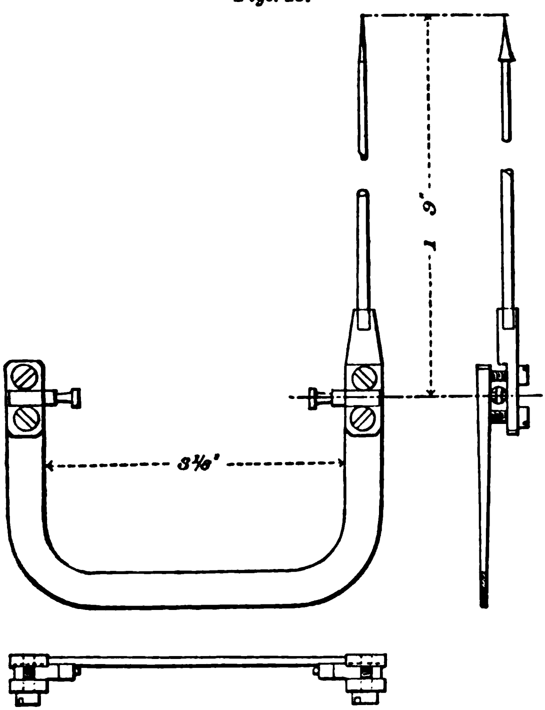
Fig. 12.



laboratory at the Central Technical College, in order to give the students a simple means of measuring the elastic strain produced in materials by mechanical tests. One of the instruments had been made almost entirely by students. The chief feature of

these extensometers was that the multiplication, needed for making small elastic extensions visible, was obtained entirely by mechanical means. The mechanism adopted was that of the oscillating steam-engine. The small arm of the multiplying lever corresponded with the crank, the bracket carrying the scale with the frame of the engine, and the specimen with the piston, piston-rod and cylinder. A small extension of the specimen was represented Mr. Ashcroft.

Figs. 13.



Half Full Size.

in the engine by a small movement of the piston in the cylinder. It was well known that the component of a small displacement of the crank pin in the direction of the axis of the engine was not quite equal to the resultant movement of the piston in the cylinder. With the dimensions adopted in these extensometers, however, the error was far less than could be detected by a scale and pointer or even with the most delicate vernier, so that for all practical purposes the mechanism might be considered perfect. Multiplying levers in similar instruments usually had the length of the short arm determined by the position of two knife-edges.

Mr. Ashcroft. In the single-lever extensometer this method was changed, the length of the short arm being the distance between the seats or bearings of the knife-edges. This enabled a very small distance (about $\frac{1}{10}$ inch) to be conveniently used for the length of the short arm, and the effect of wear in altering the leverage was greatly reduced. *Fig. 12* showed, in diagram form, the principle of the multiplying arrangement of the single lever extensometer; *Fig. 13* was a drawing of the lever and knife-edge seats. In many extensometers some of the parts, which had a small motion, were connected by means of pointed screws working in centre dots. It was sometimes found that differences in the amount by which these screws were tightened made a sensible difference in the extensions measured. In the latest form of the single-lever extensometer no joints of this kind were used. The parts between which a small motion was required were connected by pieces of thin spring steel (known as Emery springs) the friction and backlash being thereby reduced to a minimum. In these extensometers the multiplication was fairly large (200 to 1), an ordinary equally-divided scale was used, and the readings taken on the scale were proportional to the extensions of the specimen, and no corrections were required. The first reading could be taken when no load was on the specimen. No gauge-length marks or centre-dot points were required. The instrument need not be touched during a test; it was entirely supported by its attachment to the specimen, which it touched only at the points between which the extensions were to be measured. The extensometer could be used on a specimen in either a vertical or a horizontal position, or on a bar in a structure or machine in any position.

Mr. Blount. Mr. Bertram Blount was much struck by the close concordance between the observed and calculated results given in the Paper, which went far to establish the Author's view, that if test-pieces having a standard relation of length to diameter were generally employed the indication of ductility given by the elongation of the test-piece might be more rigorously interpreted than was usual. But it appeared to him that the great uniformity of the tests, while reflecting high credit on the experimenter and on the steel-makers who had provided the material for the tests, was in itself a possible source of error. If a person knowing little of the structure of steel were to examine these figures by themselves, he might be led to suppose that steel was a homogeneous material. Mr. Blount had far too much respect for the Author's knowledge to suggest that this erroneous belief would receive his countenance; transverse tests were alone sufficient to refute such an idea.

Nevertheless, the idea might be entertained by less expert users of structural metals, if attention were not drawn to its fallacy. So far from being a homogeneous material, steel was little better than a bundle of muscles and nerves. A steel ingot consisted of a mass of crystalloid grains, differing in chemical composition and micro-structure, having gaps and crevices between them, some microscopic and others relatively enormous. When this ingot was rolled, its imperfections were distributed either chiefly in the direction of its length, if a bar or rail was being prepared, or chiefly laterally, if a plate was being made. The mass of material was the same and the gaps and fissures were the same, but they were differently dispersed. A rail made from the usual imperfect ingot might be regarded as a bar built up of sound rods of metal fairly well stuck together, but having between them in parts of their length considerable solutions of continuity. A plate made from the same ingot would have similar imperfections, but they would be displaced laterally, and the solutions of continuity would not merely be distributed but would be attenuated; further they would be removed the one from the other, and fracture proceeding through these lines of weakness would have to bridge larger spaces filled with sound metal. Hence the comparative uniformity of tests obtained with plates and sheets could not be expected of material less laterally extended. He had direct experience on this point; he had found that rails which had broken in actual work, although possessing a satisfactory ductility when tested longitudinally, contained numerous and continuous longitudinal flaws; these were not apparent to the eye, but could be descried by examining a complete section of the rail under a moderate amplification. Test-pieces cut across the rail were destitute of ductility; they broke absolutely short. With this fact established it seemed reasonable to look more to the reliability of structural steel than to any particular degree of ductility. If the metal was homogeneous in every direction there would be ample justification for choosing that steel which should show the greatest ductility in an ordinary tensile test. But, seeing that the material was far from homogeneous, this was not sufficient; the metal must be tested in all directions. Further, even these tests would scarcely establish the reliability of the material; in breaking a test-bar by a slow and steady pull a fair elongation might be obtained from a metal in which numerous flaws, microscopic it might be, existed. It followed that the ordinary mechanical tests, however accurately devised, and however carefully applied, were inadequate for appraising the value of steel as a structural material. In his Mr. Blount.

Mr. Blount. opinion it was a mistake to endeavour to pronounce on the quality of steel without taking into account all the significant facts which could be obtained, by an examination of its chemical composition and of its micro-structure, as well as those yielded by its behaviour under mechanical tests. In the last heading, shock tests should be included. Shock tests on notched bars were relatively new, and on their correct interpretation there was still much divergence of opinion. But they presented a good prima facie case for consideration and could not safely be ignored. With regard to the composition and micro-structure of the metal, knowledge was both larger and more exact. First, with regard to chemical composition. The Author's view was expressed thus (p. 170):—"Chemical analysis is of great value to the steel-manufacturer, but the engineer is not directly concerned with the composition of steel, but only with its mechanical properties. It is only so far as the influence of different constituents, or percentages of constituents, has been ascertained by correlated mechanical tests, that chemical analysis is of value to the engineer. Hence mechanical tests are fundamentally the most important, and if they could be made stringent enough, it would be undesirable that the steel-maker should be hampered by specifications of chemical composition. Unfortunately, mechanical tests, as hitherto made, are not wholly satisfactory, and hence they are generally supplemented by restrictions as to chemical composition . . . As to chemical analysis, it should further be pointed out that it is becoming clear that the mechanical properties of steel depend quite as much on its structure as on its composition." To take the last statement first: the fact that the structure of steel, as well as its chemical composition, influenced the mechanical properties of the metal, gave excellent reason for studying the former, but afforded no logical ground for neglecting the latter. But the main argument needed more than an academic rebuttal. It was true that the engineer—as an engineer—was not concerned with the chemical composition of the steel which he had to use, and it was true that if steel of unexceptionable mechanical properties could be secured without reference to composition, the steel-maker might well be left absolutely unhampered. But it was also true that no mechanical tests, however well devised, or however skilfully carried out, would suffice to ensure that steel which satisfied such tests would prove reliable in practice. Fortunately, the vast mass of experience which had been accumulated since the introduction of structural steel proved that metal which fulfilled both sets of conditions—which behaved satisfactorily under the intelligent

application of all the regular mechanical tests, and at the same time possessed a composition falling within certain well-recognized limits—was (given ordinary skill and care in manufacture) so nearly absolutely reliable that the engineer who used it "might sleep on both ears." The two methods of appraising the quality of the metal were complementary, and to discard either appeared to him to be an invitation to disaster. The structure of steel had only lately received the attention which it deserved, and on this account, though recorded observations were fairly abundant, yet their correlation with the quality and behaviour of the metal in practice was not fully worked out. Somewhat tentatively, and conscious of abundant ignorance, he was disposed to believe that too much had been made of that minute structure which depended on the existence in the metal of compounds of iron and carbon, or arrangements of iron and carbide of iron, which were categorically distinguished by titles compounded of the names of eminent investigators and the suffix "ite." It would be folly to deny that inquiries in this direction were necessary and pertinent to the question of the quality of the steel; but it was perhaps not superfluous to remark that in searching for these minute and doubtful entities, glaring facts might be overlooked. A steel having an unexceptional minute structure would be valueless as a material of construction if it were riddled with cracks, and pending a precise knowledge of the meaning of each constituent of the micro-structure, search for visible and significant flaws was a useful proceeding. He thought that if, at the present state of knowledge, the homogeneity of structural steel, as determined by examination of sections in all significant directions under a moderate amplification, were ascertained, there would be given to the engineer information as positive and useful as that now constantly provided for him by properly devised mechanical tests and accurate analyses; with these three sets of data at his disposal he could decide with certainty whether the material which he was to use was reliable or not. Mr. Blount.

Dr. A. W. Brightmore wished to draw attention to the variation in the values of b and c, in the Table on p. 191, for different thicknesses of plates and for plates of the same thickness manufactured by different makers. As the Tables on pp. 192 to 194 were calculated for the appropriate values of b and c for each plate, he would suggest that the formula for extension of plates be written Dr. Brightmore.

$$e\% = \frac{f\sqrt{w}}{l} + b$$

Dr. Brightmore. where $f = c \sqrt{\text{thickness}}$ and w = width of plate, f and b being constants for a particular plate of a given thickness. With respect to the Author's remark on p. 197, that "even small differences of elongation would be significant if testing were not so roughly and unscientifically carried on," he would point out that Fig. 6, Plate 1, showed, with the same value of $l/\sqrt{A}$, for the companion specimens cut from the $\frac{7}{8}$-inch plate and the $1\frac{1}{4}$-inch plate, differences of elongation of 11 per cent. and 7 per cent. respectively; and he would therefore ask if small difference of elongation really were so significant, even when testing was scientifically carried out, when the material was of a variable nature. He would further ask whether experiments on two specimens of each thickness of plate, when the material from which they were taken was variable in quality, were numerous enough to obtain sufficiently reliable values of b and c for drawing correct inferences on such points as the variability of ductility in different thicknesses of plates? The Author did not appear to have given sufficient reason to enable others to see the justification for neglecting such results as those for plates Nos. 2372, 2388 and 2389. There was nothing, so far as Dr. Brightmore observed, to show that equally discordant results would not have been obtained among another set of specimens cut from the same plates; and it appeared to him that the existence of such imperfections should not be ignored by excluding these results.

Mr. Harbord. Mr. F. W. Harbord remarked that to those who knew the great variation there was in the specifications of engineers, it was unnecessary to emphasize the importance and usefulness of a formula giving the relation between gauge-length and area, so that the extension, measured on different lengths and varying sections, could be reduced to one standard for comparison. As pointed out at the beginning of the Paper, there was probably general agreement as to the desirability of reducing the number of tests as far as possible, and provided one, either mechanical or chemical, could be devised of sufficient delicacy to detect dangerous material with certainty, it would be of great benefit to all concerned. Useful, however, as was the information afforded by the testing-machine as an indication of the properties of the material, he did not think that any test which depended upon a gradually applied load, taken by itself, could be regarded as entirely satisfactory; and it was only when supplemented by chemical analysis, resistance to shock, or vibration tests, that it could be safely trusted. The fact that samples cut from the same plate, and

Mr. Harbord.

of the same section, would give variations in extension of 4·7 per cent., as in the case of samples 2352 and 2353 (p. 208), and the well-known fact that material containing a percentage of phosphorus which was admittedly dangerous under vibration or sudden shock, would not infrequently give excellent results in the testing-machine, showed that, taken alone, the testing-machine results could not be relied upon. It was equally true that chemical analysis alone could not be accepted, because frequently material which was perfectly satisfactory from an analytical standpoint, gave very bad mechanical results, due in many cases to the heat-treatment during manufacture. It therefore seemed that a combination of chemical and mechanical tests was desirable, and especially some simple vibration test, which would subject the material to conditions of stress like to those to which it would be subjected in practice. In specifying chemical analysis, it was most important to distinguish between impurities which were due to the use of impure materials and to carelessness in manufacture, and constituents which were either added to or left in the metal in order to give it the required properties. Thus phosphorus and sulphur were impurities whose effect would depend largely upon the materials used; and the engineer was exercising only reasonable precautions when he insisted upon these being reduced to the lowest possible limits, as they never improved the quality of the steel, and when present to any extent were very dangerous. On the other hand, carbon, manganese and silicon, might be regarded as necessary constituents, and these had to be varied by the steel manufacturer in order to produce a steel to meet the mechanical requirements of the specification. When chemical analysis was specified, therefore, while the phosphorus and sulphur might reasonably be limited, the carbon, manganese and silicon, should be fixed only after consultation with the manufacturer, as otherwise he might be asked to fulfil impossible conditions. The American specifications were drafted on these lines, rigid limits being fixed to the phosphorus and sulphur, while either the carbon was not specified at all, or else this and the other essential constituents were specified within such limits that any manufacturer with care could work to them. With regard to the advisability of specifying a higher limit for the tensile stress, provided manufacturers could produce regularly a material of greater strength without loss of ductility, it would obviously be a great gain to engineers; but in the present state of the art this was not possible, and such steel when produced might be regarded as exceptional and abnormal. At present, except

Mr. Harbord. in cases of special alloys, high tensile stress was obtained by increasing the percentage of carbon or manganese. The latter was always liable to give an unreliable material, and the former produced a steel which took temper, which was most undesirable for boilers and some other purposes. Practically it was found that the elongation and tensile stress varied together, and if the higher limit were dispensed with, an additional check was done away with, and reliance had to be placed upon elongation alone, which appeared to him to be undesirable. With respect to the decrease in ductility in the thick plates, although this was regular, it was never more than 6 per cent., and generally less. The results given in the Appendix showed that there was a variation of 3 per cent. to 4 per cent., and in one or two cases nearly 5 per cent., in duplicate plates of the same sectional area and the same form. He would like to ask whether the Author considered that the elongation results given on p. 186 could be in any way due to the skin on the plates. The $\frac{3}{8}$-inch plates, 0·5 square inch in area would be about 0·375 inch thick, with a width of 1·336 inch with surface skin on; in the $1\frac{1}{4}$-inch plates the width with surface skin on would be only 0·4 inch. In the case of round bars tested with the skin on, the elongation was generally greater than in the same bars turned; and it was possible that the same effect might explain the elongation of these plates. Suitable heat-treatment would restore almost completely the ductility of material which had been rendered brittle; but no heat-treatment could render steel good which was chemically bad, although even in such cases it might frequently be improved. The finishing temperature in rolling or forging had a marked influence on the physical properties of the steel, and modern research pointed to the fact that heat-treatment had more influence on the physical properties than work, provided a reasonable amount of the latter had been put upon the finished plate or bar. By varying the heat-treatment, the elastic limit, and ductility as shown by the extension, could be varied within wide limits, and the conditions both as to heating and rate of cooling had a marked influence on the general properties. Steel castings which were quite brittle as cast could be made by heat-treatment almost as ductile as forged material, the whole structure as shown by the microscope being changed.

Mr. Houghton. Mr. Sidney A. Houghton was glad to see that the Author had called attention to the possibility of time errors occurring in testing. Many people seemed to regard the figures on test-sheets as if they were produced by a calculating machine, and appeared to

be unaware that the results could be materially influenced by the highly-skilled—sometimes, perhaps, too highly-skilled—operator. Quite recently an example had been brought to his notice, in which a difference of 1½ ton per square inch had been intentionally obtained between two test-pieces taken close together from a mild-steel forging. It would therefore add to the value of the Paper from a practical point of view, if the Author would give a few figures showing the possible range of tensile strength and elongation which could be obtained by varying the rate of straining in, for example, an ordinary single-lever testing-machine. The equation given for elongation was probably the only one possible without introducing great complications, but it was open to the serious objection that, as stated, unless the constants were altered it was not applicable to more than one class of steel. As the quality of carbon steels varied continuously with the increase in the amount of carbon, there was no such thing, theoretically, as a class, and it was evident that the constants ought also to vary continuously. The Author referred in a rather slighting manner to the quantity known as contraction of area, and stated that it was liable to be affected by small defects in the test-piece; but if that were so, the elongation would also be unreliable, as the first quantity in the elongation-equation was simply a function of the contraction of area. As mentioned in the Paper, the latter and the elongation were two dissimilar measures of ductility, and therefore it would be well to emphasize the point that the elongation, as usually measured, was the sum of these two dissimilar qualities—or of functions of them—the contraction of area and the real elongation. In view, therefore, of the compound nature of the so-called elongation, it seemed desirable to record the contraction of area as often as possible, if only in order to estimate the elongation properly so called. This could then be readily done, as it was only necessary to ascertain what function of the contraction of area for a given class of steel the length of the contracted part represented, and then, knowing the diameter of the test-piece, the length referred to could be calculated at once. The contraction of area was frequently a better measure of ductility than the elongation, as, for instance, in the case of insufficiently annealed steel castings; and Mr. Deshayes had pointed out that this was also the case with mild steel high in phosphorus—a very dangerous material. There was a question in regard to tensile tests to which reference was not made, and that was, whether the tensile strength per square inch did not vary to some extent with the area and possibly also with the length of the test-piece. He hoped Mr. Houghton

Mr. Houghton. the Author would give his opinion on this subject, as there were many tests on record which seemed to point to an influence of this nature. For instance, in the discussion on Mr. Hackney's Paper, Sir Benjamin Baker had given[1] some remarkable results of tests which merited close attention. In one example a test-piece, 8 inches by 1 inch by 1 inch, gave 27½ tons per square inch, while the whole bar, which was 16 feet by 10 inches by 1 inch, gave only 18 tons per square inch, a difference of 9½ tons per square inch. The Author seemed to be in doubt as to the object or wisdom of the upper limit of strength, which was inserted in most specifications. There appeared to Mr. Houghton to be at least three good reasons for this limit:—(1) The usual tensile test was not infallible in detecting brittle material; and though such cases were not numerous with mild steel, there was a distinct probability that they would increase cousiderably if harder steel were used for the same purposes as mild steel, and passed solely on the elongation obtained. (2) Increased carbon required greatly increased care, and also variation in any heat-treatment to which the steel was subjected, and consequently with a wide range, say 10 tons, a considerable quantity of material might easily be spoiled by the user, or even by the manufacturer. (3) For some purposes steel of a higher tensile strength was even weaker than that of less tensile strength. This seemed a somewhat anomalous statement; but percussive notched-bar tests made by Mr. Yarrow had shown that medium-steel bars failed with a much less number of blows than mild-steel bars. The Author certainly stated that such tests were not tests of ductility; but whether that was so or not, there was no doubt that they closely represented the conditions of actual practice in many cases. As an example, he would mention propeller-shafts, which probably failed more frequently than any other parts of machinery. The stiff liners fitted to these shafts produced a discontinuity of strength very similar to the notch in the test-bar; and, in a heavy sea, or when the vessel was lightly laden, the shaft, especially if the bearing was worn down, was exposed to violent blows at the after end, which sometimes fractured it in the same manner as was done in such percussive tests. This instance also afforded an example of theory following practice; for although accounts of notched-bar experiments had only recently been published, yet for many years some superintendents had specified iron or very mild steel for shafts, as

[1] Minutes of Proceedings Inst. C.E., vol. lxxvi. p. 95.

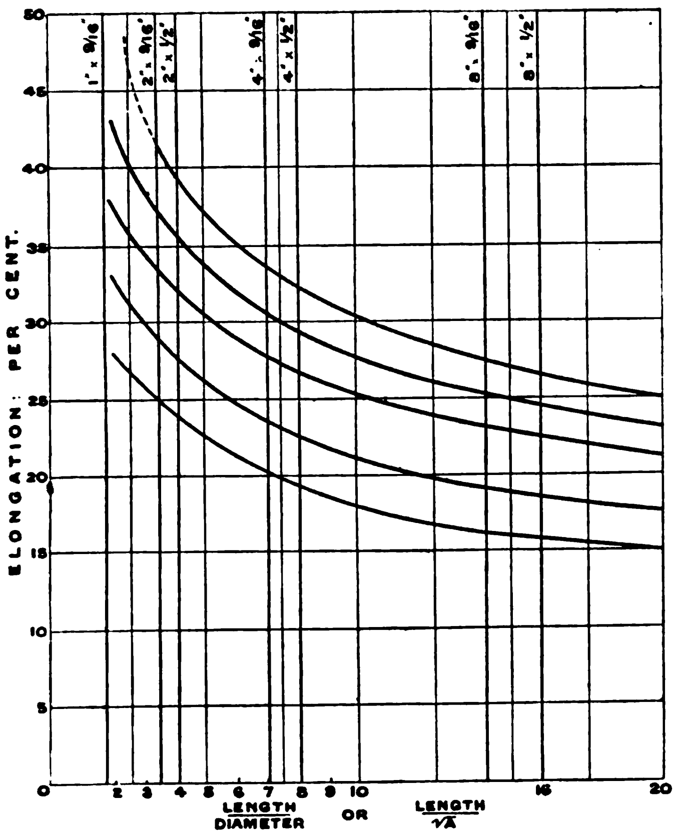
Mr. Houghton. being more reliable, in their opinion, than steel higher in carbon, although the quality-factor of the latter material was considerably higher. The fact was that, although the measure of quality given by the tensile strength and elongation was, as a rule, satisfactory, yet it was not all-sufficient. Material which had seemed good, judged by these standards, had failed in the past, and failures of the kind still occurred; not very frequently, perhaps, but still sufficiently so to show that such tests were not an absolute guarantee of freedom from brittleness. Moreover, in ninety-nine cases out of a hundred, when mild steel failed in practice, there was no elongation and no contraction of area. This showed that the metal was nearly always stressed and strained in a different manner from what occurred in a tensile testing-machine: consequently, it would be well not to exaggerate the importance of these tests. He thought therefore that the Author was too sanguine in suggesting that if the tensile test were made more accurately, other tests might be dispensed with. In recent years several investigators had turned their attention to notched-bar, fatigue and other tests. Personally, he looked forward with interest to the results of such fatigue-tests as were being made by Mr. J. E. Stead, with a view to establish a correlation between really reliable material and its structure. Such tests took a long time to make, but if it were known from the experiments what the structure of good steel should be, it might be possible in the future to eliminate defective material by a microscopical examination, which could be made in the time taken to prepare a tensile test-piece. Although it was desirable to reform the conditions of some tensile tests, yet care must be taken not to build a wall of protection round them; rather, free trade in tests should be aimed at, which alone would ensure that the user would be able to employ those which most nearly approached the conditions of actual practice.

Mr. Izod. Mr. E. G. Izod remarked that to many engineers the Paper would shed new light on an old subject, but its great value could only be appreciated by those who were in constant touch with the actual tests themselves, and, what was perhaps more important, with the interpretation of the results. Every one who was doing such work must at some time have felt that a kind of indefinable inaccuracy or contradictory evidence had crept into the results which could not be explained away by any known rules or data; the terms were there in black and white, and were often accepted as final, with, however, a shadow of a doubt as to their reliability. The Author had now given a clue to the solution of a large number of inexplicable test-results, and if the Paper were carefully followed

Mr. Izod. it would be found that the ductility of mild steel could be clearly defined. On looking through records of tests it was impossible to avoid being struck with the callous way in which the ductility, as measured by elongation, was expressed in many cases as elongation per cent., not only omitting the diameter of the test-piece, but actually the length between gauge-points, with the consequence that the test had practically no value beyond the strength figure, and even this was of little use without the elongation per cent. About 2½ years ago it had been found desirable, in the works of Messrs. Willans and Robinson, at Rugby, to lay down some definite line which would make all tests strictly comparable. The fact that this line agreed with that laid down by the Author, and was working with absolute satisfaction, would perhaps go some little way to prove that the scheme was a workable one; and it would further be found to be absolutely necessary, if an accurate value was to be attached to the results obtained. On looking closely into the question of the variation of the percentage of elongation with different test-bars, there had seemed to be a hitch somewhere which required straightening out, and the following method had been adopted. From experiment, experience and sundry data, a set of curves had been drawn, the ordinates representing elongation per cent. and abscissas l/d for round, and $l\sqrt{a}$ for flat specimens; l being the length between gauge-points, d, diameter of test-piece, and a, area as computed from rectangular specimens. Then, knowing the cross-sectional area and test-length, it had been quite easy to transfer any elongation per cent. to an equivalent for the test with which it was necessary to make a comparison. The curves shown in *Fig. 14* were much the same as those given in Fig. 6, Plate 1, though they would be more valuable if they could be plotted as straight-line curves in the method adopted by the Author. After obtaining these curves, it had been found advisable to use a standard test-piece, to which all results could be equated, and which would give a direct measure of comparison with any test, when the test-length and cross-section were known. The standard size of specimen adopted had been found to give the best all-round value with $l = 2$ inches and $d = \frac{9}{16}$ inch, the ratio l/d being curiously enough $3 \cdot 55$, which was practically identical with that advised by the Author (p. 200). With these data it had been possible to use dimensions for the test-piece which were most suitable (endeavouring always, of course, to adopt the standard); and the percentage of elongation had then been calculated, and quoted as "equivalent elongation per cent. on standard." This method of correcting or balancing

the results had proved so satisfactory that no importance was now attached to a test unless the actual test-length and diameter was known, when it could be transferred to an "equivalent" and a direct and reliable comparison could be drawn as to its value. On p. 175, the Author remarked: "Percentages of elongation of two Mr. Izod.

Fig. 14.



EQUIVALENT ELONGATION CURVES.

bars are not strictly comparable unless fracture occurs at similar points in each. But in practice fracture occurs at various positions between the gauge-points." This was another very important point that was too often neglected; but it had been noticed that in a test-piece having $l = 2$ inches, fracture occurred so near the mid-position nearly every time that the difference in elongation

Mr. Izod. expressed by the position was almost negligible. Of course, if fracture occurred at a dot, it was advisable to reject the test. On p. 179 it was suggested that the general elongation or elongation at the moment of maximum load be taken as the measure of the ductility, and it would be interesting to know whether the Author advocated measuring the elongation at the actual instant the maximum load was reached, or later, as it could sometimes be seen from an autographic diagram that the curve was flat-topped; in other words, the maximum load was constant for a time, while the elongation was still taking place. The quality-factor suggested on p. 202, was a doubtful quantity, and, as the Author said, applicable only within limits. These limits were so narrow that a common-sense factor might also be said to take the place of the quality-factor. There were so many qualifications necessary in a suitable material that it seemed almost hopeless to attempt to express the entire character of a steel by a single quantity.

Prof. Martens. Professor A. MARTENS was very glad that the Author had dealt so convincingly with his subject, which did not receive the attention it merited, in spite of the continued efforts of national and international associations for the testing of materials. The points raised in the Paper were, however, equally important from a scientific and practical point of view. It was absolutely necessary that regard be had to them in the conduct of scientific investigations into the properties of all tough and plastic materials which experienced considerable local deformation before final rupture. Without accurate information as to the forms of the test-bars, the amounts of the ultimate extensions were useless and misleading, as, being influenced by the geometrical proportions of the bar, they could not form a basis for judging of the quality of the material.[1] For practical purposes, the manufacturer had a special interest in the method of determining the ultimate extension, and this was rightly pointed out by the Author.[2] It gave him great satisfaction to learn that the Author was of decided opinion that the so-called coefficients of quality could be accepted as criterions of the material only with many and important limitations.[3] He went further, and would say that a coefficient of quality obtained from the results of a one-sided method of test was of no more use in deciding whether a material was good or bad than a statement as to the ultimate tensile strength

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[1] A. Martens, "Handbook of Testing Materials," § 140. Translated by G. C. Henning. New York and London, 1899.

[2] *Ibid*, § 132.

[3] *Ibid*, §§ 432–435.

Prof. Martens.

alone. It was indeed in every case clearer and more intelligible to give the separate details of the test than the coefficient of quality. A boiler-plate might very easily conform to all the requirements of the usual specification—for Germany, for example, the so-called Würzburg standards—and nevertheless be dangerous, if actually used in a boiler. In a recent particular case the brittleness of the material had not been revealed by either the tensile or bending-tests, or the punching-test. It was only after making analyses and microscopic examinations of pieces from different layers of the plate, that the reason for this dangerous quality had become apparent. He wished to take this opportunity of drawing attention to another method of stating the results of tensile tests —a method which he had first proposed in his "Handbook of Testing Materials."[1] This was the evaluating of the ratio $\frac{\text{yield limit}}{\text{breaking strength}} = \frac{\sigma_s}{\sigma_B}$, which gave a sure measure of the mechanical work—stretch—the material had undergone before the test. It was easy to recognize whether the material being examined was in its unhardened, natural condition or not, for in iron that had been annealed the chemical composition appeared—within the usual limits—to have no great influence on the value of $\frac{\sigma_s}{\sigma_B}$. He had fully discussed, in his "Handbook," the results obtained in his own investigations and in those of others regarding the effect of the form of the test-bar, and the general methods pursued in testing, on the results finally obtained, and he had pleasure in citing that work as confirming the statements brought forward in the Paper. Another point, not earlier considered, was that the heat derived from the molecular work of permanent deformation of the bar must, along with the speed of testing, have an important influence on the ultimate extension. There was also the heat of the bar itself to be considered. *Fig. 15* would serve to make these points clear; it showed the ultimate extensions ($\delta_{11\cdot3}$), and the contractions of areas (q) obtained in the testing of three different qualities of steel, the bars being 20 millimetres (0·8 inch) in diameter and their gauge-length 200 millimetres (8 inches). The bars had been broken at temperatures varying between 20° C. and 600° C.[2]

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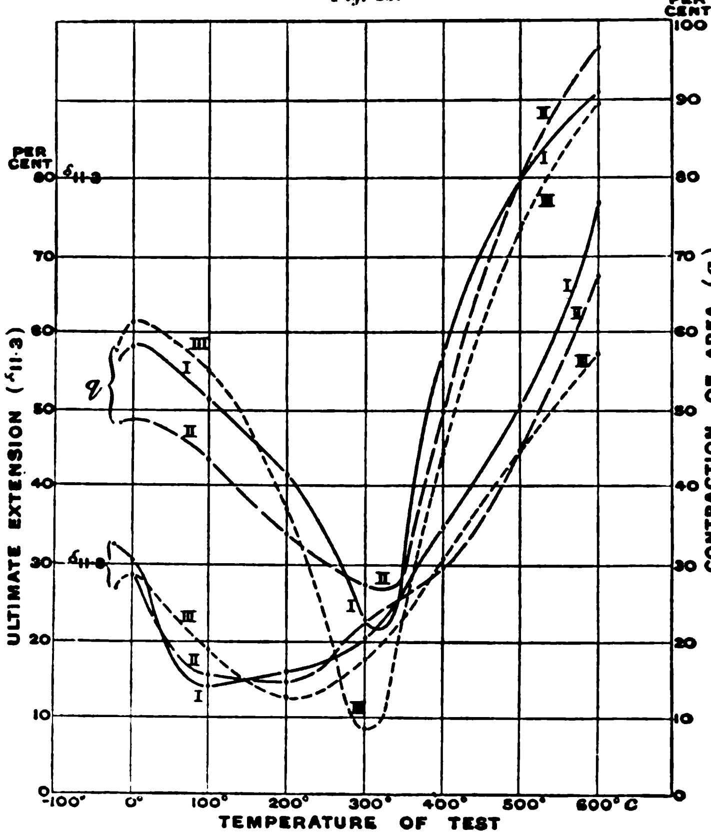
[1] "Handbook of Testing Materials," §§ 426 and 365.

[2] A. Martens, "Investigations on the influence of Heat on the Strength and Elasticity of Iron." Mittheilungen aus den Königlichen technischen Versuchsanstalten zu Berlin, 1890, p. 159. (Translated in Minutes of Proceedings Inst. C.E., vol. civ. p. 209.)

Prof. Martens. It would be noted that between zero and 50° C. the lines fell rapidly, showing that the ultimate extension was already markedly affected by a difference of a few degrees in the surrounding

Fig. 15.



			Kilograms per Square Millimetre.	Tons per Square Inch.	
I. Mild steel . .	Yield limit . . .	σ_s =	22·6 =	14·38	$\frac{\sigma_s}{\sigma_B} = 0\cdot59$
	Tensile strength .	σ_B =	38·4 =	24·35	
II. Normal steel .	Yield limit . . .	σ^s =	24·1 =	15·26	$\frac{\sigma_s}{\sigma_B} = 0\cdot55$
	Tensile strength .	σ_B =	43·7 =	27·74	
III. Hard steel . .	Yield limit . . .	σ_s =	26·9 =	17·07	$\frac{\sigma_s}{\sigma_B} = 0\cdot57$
	Tensile strength .	σ_B =	47·0 =	29·8	

$\delta_{11\cdot3}$ = Ultimate extension measured on a gauge-length $l = 11\cdot3\sqrt{f}$ (f = area of cross section).

q = Contraction of area as percentage of f.

INFLUENCE OF TEMPERATURE ON THE STRENGTH OF STEEL.

temperature.[1] The heat of the bar had, however, great influence on the contraction of the cross section, and as this was in a constant ratio to the extension,[2] it ought also to be concluded that the elongation was affected by the heat developed during the stretching of the bar, and therefore by the rate at which the deformation of the bar proceeded; because, in a rapid test, the whole amount of the heat was developed in a short time, and, not having time to become dissipated, it caused a rise of temperature in the bar. Experiments on this point were of decided practical interest. There was one subject brought forward in the Paper which he also had found, after years of experience, to be of the greatest consequence; that was, the testing of the degree of accuracy of the machines and of the measuring-instruments. In the numerous machines examined at the Königliche technische Versuchsanstalt at Charlottenburg, errors of as much as 20 per cent. had been found. With regard to the footnote on p. 184, his statements, and also § 146 of his "Handbook," were based on the experience gained during very many experiments on the influence of the form of the ends of bars on their deformation. Prof. Martens.

Mr. JAMES N. SHOOLBRED remarked that the Author divided the tests for quality into four kinds—chemical, mechanical, workshop and microscopical. Of these he appeared to consider mechanical tests to be the most important; so much so that they should, if possible, be made even to override the chemical analysis. He would ask whether, when making the various tests described in the Paper, the Author had overlooked the investigations carried out about 20 years ago by a Committee of the Institution of Mechanical Engineers on the Hardening and Tempering of Steel; also two Papers by the late Professor D. E. Hughes, namely, "On the Molecular Rigidity of Tempered Steel," communicated to the Institution of Mechanical Engineers in 1883, and "On the Physical Condition on Iron and Steel," in 1884. Both of these, when read, had been accompanied by a number of interesting experiments, whereby Professor Hughes had shown, by means of a magnetic induction-balance, that, mechanically, the structural density, as well as the relative internal mobility of the constituent molecules of various kinds of iron and steel, varied considerably. For instance, while with tempered cast steel the rigidity showed a Mr. Shoolbred.

[1] So far as he was aware, this circumstance had not hitherto been tested by comparative experiments.

[2] The specific weight of a ductile material suffered only an exceedingly slight change during the production of the permanent deformation ("Handbook," § 26).

Mr. Shoolbred. range of but 15 divisions on a certain scale, the rigidity with soft iron indicated as much as 3,776 divisions on the same scale. The magnetic induction balance acted, in fact, in this case—as did the phonograph in the telephone—by increasing very largely the effect of torsion, or other disturbance among the molecules of the structure, the resultant action being a purely mechanical one. Seeing, therefore, the importance attached by the Author to the mechanical tests, might not an instrument such as Professor Hughes had used be employed with advantage in mechanical investigations into the structure of iron and steel? The late Sir William Roberts-Austen had testified to the great advantage he had found, at the Royal Mint, from the use of Professor Hughes's induction-balance, as a means of rapid investigation. So much so, that its use there often did away with the necessity for chemical analysis, as the balance at once revealed the character of the molecular structure. With regard to the question of temperature, Professor Hughes, in his two Papers, showed that, in the operations of annealing, the temperature of the test had a marked effect on the rigidity of the structure, that was, upon the closeness of the internal molecules, and likewise upon the magnetic capacity, as evidenced by the different proportions of the several chemical compounds. Further, the investigations of Professor Dewar into low temperatures, down to about – 240° C., and of Professor Callendar on high temperatures, showed that the variations in electrical resistance, which practically meant the rigidity of the molecules themselves, altered very much. Professor Dewar had also shown that both the breaking stress and the rate of elongation varied considerably with the temperature of the metal. Again, did the testing of boiler-plates, at an ordinary temperature, say 60° F., represent the condition of the constituent molecules of those plates, when in actual use in the boiler at some 400° F.? The investigations of Professors Dewar and Hughes would seem to answer this question in the negative. But, likewise, Professor Hughes's induction-balance would appear to be able to indicate the mechanical differences in the internal structural condition of the plates, at the different temperatures—a matter which was certainly of much importance.

Mr. Webster. Mr. WILLIAM R. WEBSTER did not agree with the Author that the engineer was not directly concerned with the composition of steel, but only with its mechanical properties; for the 'ue of steel depended on, first, its chemical composition, and ɩd, the heat-treatment it received in forging and rolling.

One was of as much importance as the other. The engineer did not test every piece of steel, but relied on a few tests to show the general character of the whole lot or heat under consideration. It was necessary to start with steel of good, known, chemical composition, if such tests were to show the average quality. The changes due to segregation would also be less in such steel than in steel higher in impurities. This certainly was of importance to the engineer; but he need not carry the chemical requirements to such hair-splitting refinements as appeared in some specifications. With a good uniform steel, chemically, and proper care taken in the heating and rolling or forging, the best results were obtained in the finished product, and it was no great hardship for the steel-maker to comply with reasonable chemical requirements, and with the upper and lower limits of tensile strength with a variation of, say, 10,000 lbs. per square inch. The steel-maker knew from the chemical composition what results he might expect from the physical tests, with a given heat-treatment, and if such results were not obtained, it was an easy matter to locate the trouble and correct it. On the other hand, if no attention was paid to the chemical composition, and it was not necessary to comply with anything but the low limit of tensile strength and minimum elongation, the resulting material would vary much more in its physical properties, and there would be more failures in shop-treatment and in service. The results given in Mr. H. H. Campbell's recent book on "The Manufacture and Properties of Iron and Steel" confirmed those of the Author, by numerous Tables, in that the elongation was increased by increasing the width of the test-piece. This was well understood in America, and was one reason why the Committee of the American Society for Testing Materials had adopted a standard width of test-piece in their specifications, namely, 1½ inch. They also provided for the allowance in elongation for material of different thicknesses thus:— Mr. Webster.

"For material less than $\frac{5}{16}$ inch and more than ¾ inch in thickness the following modifications will be made in the requirements for elongation:—

(a) For each increase of ⅛ inch in thickness above ¾ inch a deduction of 1 per cent. shall be made from the specified elongation.

(b) For each decrease of $\frac{1}{16}$ inch in thickness below $\frac{5}{16}$ inch a deduction of 2½ per cent. shall be made from the specified elongation."

In addition to this, the following provision was made for cases where the fracture did not occur at or near the centre of the specimen:—

"One tensile test specimen will be furnished for each plate as it is rolled, and two tensile test specimens will be furnished from each melt of rivet rounds. In case any of these develops flaws or breaks outside the middle third of its gauged length, it may be discarded, and another test specimen substituted therefor."

Mr. Webster. Other specifications called for the same elongation on all thicknesses of material, using one width of test-piece, but specifying shorter gauge-lengths on which to measure the elongation, as the thickness increased. In ordinary commercial testing one width of test-piece was of great advantage in facilitating the preparation of the large number of test-specimens required; allowances could be made for the proportion of width to thickness of test-piece, and also for the difference in quality due to differences in finishing temperature between the thick and the thin material; that was, both of the above could be taken into account in specifying the elongation. Even if test-pieces of different width were used, the allowances referred to above, due to differences in finishing temperature, must be taken into account, unless the elongation specified was low enough to cover all cases. To sum up, even though the elongation were taken by the most improved method, it could not be relied upon as an absolute check on the quality of the steel. There were cases in which steel finished at too high a temperature would show a satisfactory elongation under the slow pulling of the testing-machine, and would not give satisfactory cold bends. Such material was liable to fail in working, in the shop or in service. Therefore cold bends on the material, in the condition in which it left the rolls, should never be omitted, as they formed the most reliable check there was on brittleness. The quench bend would not take its place as it gave very misleading results.

Mr. Wingfield. Mr. C. Humphrey Wingfield observed that it was suggested on p. 171 that mechanical tests might be so far perfected as to render chemical tests unnecessary for the purposes of engineers. He had found, however, that for some purposes (*e.g.*, the selection of water-tube boiler material to offer the maximum resistance to corrosion) mechanical tests told little or nothing, while chemical, and, still more, microscopical examinations were very valuable. The following bibliographical notes might be of interest. Professor Belelubsky published in 1891 an investigation[1] wherein he obtained a method and formulas by which, either by plotting or by calculation, the elongation of a given test-piece could be expressed in terms of the corresponding elongation of a differently proportioned test-piece of the same material. Dr. R. C. Carpenter in 1895 published diagrams[2] for the same purpose, the diameters of the test-pieces being, however, constant, and their lengths ranging

[1] Transactions American Society Mechanical Engineers, vol. xiii. p. 289.

[2] *Ibid*, vol. xvi. p. 904.

Mr. Wingfield.

between 2 inches and 8 inches. No calculation was necessary when these diagrams were available. Dr. Carpenter at the same time pointed out that the extension at maximum load was independent of the gauge-length of the specimens. He also gave a diagram for finding the elongation at maximum load when the final elongation of a $\frac{5}{8}$-inch diameter specimen was known. These diagrams appeared to indicate that a part only of *b* in the Author's formula and diagram represented the extension at maximum load. The footnote on p. 183 showed a curious instance of two investigators arriving at identical conclusions, as so often happened. Professor Martens appeared to credit Bauschinger with the authorship of the formula in question.[1] Dr. Carpenter's diagrams seemed to indicate that while the Author's straight-line formula applied to rectangular test-pieces it did not apply to the round bars tested by Dr. Carpenter. Perhaps the Author could throw some light on this. If the quality-factor were taken as $f+c$ and a number of samples had the same quality-factor of, say, 60, then, three pieces of which the first might have an ultimate strength of 60 tons and no elongation, the second an extension of 60 per cent. and insufficient strength to carry its own weight, and the third an ultimate strength and elongation each equal to 30, would rank as equally good. A reliable quality-factor was an exceedingly difficult thing to decide upon, and he feared that the desired result was still unattained. As Mr. Barba had found so definitely that a rectangular test-piece gave a greater elongation when six thicknesses wide than when wider or narrower than this, it was strange that neither the Author nor Mr. Appleby[2] was able to confirm this result. On p. 180 the Author gave $11 \cdot 3\sqrt{A}$ as the German standard for the gauge-length of specimens, and on p. 200 he suggested making it $4\sqrt{A}$ for short specimens. Was there any physical reason for a particular length being chosen as the standard? The decimal place in the German standard seemed to suggest that there was. The Author suggested the method of least squares for arriving at the values of *a* and *b*. Would it not be simpler to plot a diagram like *Fig. 5*, measure *b* directly and find *a* by dividing the height of the triangle by its base?

The Author.

The AUTHOR, in reply, desired in the first place to express his appreciation of the remarks of Professor Martens. Little was said in the Paper about the ratio of yield-limit to breaking stress, not because it was unimportant, but partly because it was not generally

[1] Martens, "Handbuch der Materialienkunde," § 146. (English translation by G. C. Henning, p. 123. New York, 1899.)

[2] Minutes of Proceedings Inst. C.E., vol. cxviii. p. 407.

The Author. in England made a matter of specification, and partly because the determination of the yield-point in ordinary testing was, in the Author's opinion, not made in a satisfactory way. Professor Martens's remarks on the influence of the temperature were very interesting, and it was hoped he might give some quantitative results on this matter. It was well known that the total extension was not in any direct proportion to the contraction of area, but there should be some correspondence between the local extension and contraction of area. So far as the Author had observed the correspondence was less close than he expected. Dr. Brightmore proposed to substitute $f = c\sqrt{t}$ in the elongation equation under the impression that f would be constant for plates of different thickness. This would be to substitute an empirical for a rational expression. It was clear from Barba's results, Table 4, p. 172, and from other tests made by the Author, that with the same quality of steel the local extension varied directly as $\sqrt{A}$, and that f was not constant. That in some of the tests in the Paper it happened that $f = c\sqrt{t}$ was approximately constant was an accidental result of the particular conditions of rolling of these plates; and to substitute f for $c\sqrt{t}$ would be to mask the variation of quality which was exactly what the engineer required to know. The Author attributed the variation of ductility with thickness to a difference of structure, and a microscopic examination showed that there was such a difference in these plates.[1] Mr. Houghton thought that there should be free trade in tests: but nothing could be more mischievous than that steel-makers should be required to comply with different and inconsistent test-conditions imposed by each different engineer. It was the object of the Engineering Standards Committee to obviate that. The Author was glad of the confirmation of his results by the experience of Mr. Izod, but he would point out that the reduction of results to "equivalent on standard" was a proceeding the limits of accuracy of which required to be established. If elongations were measured on two gauge-lengths, such reduction could be effected with considerable certainty. But if only one gauge-length was measured, the reduction by standard curves might in some cases be misleading. As to the general elongation, the Author would measure it at the point where the load began to decrease, because up to that point the elongation was general along the bar. Mr. Wingfield's statement that the Author suggested that chemical tests were unnecessary for engineers exaggerated the state-

[1] See footnote, p. 241.—Sec. Inst. C.E.

ments in the Paper. Chemical tests would always be necessary for steel-makers and to engineers in special cases. The only question raised in the Paper was as to the desirability of including them in ordinary specifications such as those for ship-material and structural steel. For Mr. Wingfield's information it might be pointed out that the constant 11·3 had arisen out of a very simple consideration. The German normal test-bar was 200 millimetres long and 20 millimetres in diameter, and in that case $l = 11 \cdot 3 \sqrt{A}$. The matters referred to by Mr. Shoolbred were interesting, but they were rather outside the scope of the Paper which was concerned with ordinary commercial testing. Mr. Harbord, Mr. Webster, and Mr. Blount had all written defences of chemical analysis as a means of determining the trustworthiness of steel. To a large extent the question of chemical analysis was irrelevant to the subject of the Paper. No one doubted that chemical research would throw some light on the quality of steel, because a more or less exact correlation had been established between composition and mechanical properties, by numerous comparisons. But the only question raised in the Paper, and that very incidentally, was whether a standard chemical analysis should be imposed on steel-manufacturers in engineers' specifications. It had been not uncommon to specify limits of percentage of carbon, manganese, silicon, sulphur and phosphorus, and unfortunately the limits required had varied very much from one specification to another; and this, while extremely troublesome to the steel-maker, did not seem likely to ensure uniformity of quality in the steel. The chemist knew nothing of the effect of different constituents on the mechanical properties of steel, except by comparison of analyses and mechanical tests; so that at best the chemical evidence of quality was indirect. If there was any single constituent supposed to be generally deleterious and to produce brittleness, it was phosphorus, and there was no doubt a good deal to be said for imposing a limit to the amount of phosphorus, as was done in the American standard specifications. But while in those specifications the phosphorus was only limited to 0·1 per cent., in most English specifications it was limited to 0·06 or 0·08 per cent., and it was not clear that English steel was better than American steel. It appeared that phosphorus might exist in steel in two conditions, one of them innocuous; and Sir W. Roberts-Austen and Dr. Thorpe had come to the conclusion[1]

The Author.

[1] "Report of the Committee appointed by the Board of Trade to enquire into the Loss of Strength in Steel Rails through use on Railways," p. 111. London, 1900.

The Author. that, as regarded the influence exerted by the phosphorus, it seemed almost certain that, except in a broad, general sense, the brittleness of steel did not depend on the total quantity of phosphorus present. In the same Report Sir Lowthian Bell gave[1] some tests of rails comparatively high in phosphorus, which bore impact tests well. It was known that small differences of percentage of some constituents imposed in a specification might shut out whole districts from being able to supply the material required. But in all probability, with so complex a constitution as that of steel, differences of composition in steel made from different ores, might be advantageous and not a sign of untrustworthiness. The engineer had only to do with mechanical qualities of steel, and if these could be adequately tested he could safely disregard opinions on its trustworthiness which were based on the quite indirect evidence of composition. Mr. Webster quoted part of the American standard specifications, but he omitted to point out that in most of them no analysis was specified, and chemical conditions were reduced to limiting the percentage of sulphur and of phosphorus; also that the limits imposed for these would in England be generally considered by chemists to be too high. However this might be, the steel-maker must work more or less by chemical analysis in mixing his materials, and it was to his interest to find out what composition yielded the best mechanical results. To the engineer it was of no importance what the composition of his steel was, so long as its mechanical properties were good. In imposing chemical tests he was likely to hamper the steel manufacturer without gaining any advantage, provided only mechanical tests could be made adequate. It needed hardly to be said that though the Paper dealt almost entirely with tensile tests, which would always be important, the Author was not of opinion, as seemed implied in some of the criticisms, that mechanical tests should be restricted to tensile tests. Mr. Webster stated that the variation of elongation with width of test-bar was well understood in America. If that was so, it was the more surprising that in the American standard specifications, which were in many respects in advance of past practice, the irrational rule of a constant width of test-bar for all thicknesses of plate was adopted. Nor was this at all adequately compensated for by the empirical allowance of variation of elongation in very thick and very thin plates. Mr. Blount thought the uniformity of the results of the tests would

[1] "Report," etc., p. 78.

lead a person to suppose that steel was a homogeneous material and that this was a fallacy; and, further, that "transverse tests alone were sufficient to refute such an idea." By "transverse tests" the Author supposed that Mr. Blount meant notched-bar tests; but these were not transverse tests in the sense in which that term was ordinarily used and until the nature of the straining action in notched-bars was better understood they could not be adduced to prove that steel was not homogeneous. Exactly the opposite conclusion was probable, the more homogeneous material resisting less than less homogeneous material in notched-bar tests. Unhomogeneous wrought iron had about double the resistance of very good and homogeneous mild steel. Mr. Blount's statement that the great uniformity of the tests reflected high credit on the experimenter, and on the steel-makers who had provided the material for the tests, conveyed an innuendo which was not justifiable in a scientific discussion. Mr. Blount stated that no mechanical tests, however well devised, would suffice "to ensure that steel which satisfied such tests would prove reliable in practice." This was merely a dogmatic statement, and, in the Author's opinion, there was ample experience to show that it was erroneous. No doubt some cases had occurred in which steel which had passed the usual somewhat rough mechanical tests afterwards proved unreliable in use. Even these cases were not numerous, and it was notorious that in such cases chemical analysis, as ordinarily carried out, had also failed to indicate any reason for suspecting the quality of the steel. The chief point in Mr. Blount's criticism, however, was to throw some doubt on the importance of investigations on the structure of the steel, and to insist on the importance of the examination of the small and generally microscopic flaws in the steel. Too much, said Mr. Blount, had been made "of that minute structure which depended on the existence in the metal of compounds of iron and carbon or arrangements of iron and carbide of iron," and, on the other hand, "search for visible and significant flaws was a useful proceeding." Now, in the face of the fact, that a mere alteration of structure, as in the processes of tempering and annealing, an alteration very visible on microscopic examination, could completely alter the mechanical properties of a given piece of steel, it was impossible to believe that the general structure of the steel was an unimportant condition of its trustworthiness for the purposes of the engineer. It might be that the structure was not yet well enough understood for a specification to be made of the characteristics of good and bad quality. But that the mechanical qualities The Author.

The Author. of steel did depend on "arrangements of iron and carbide of iron," was beyond question; and, indeed, a considerable step had been taken in correlating the microscopic structure and the mechanical properties. On the other hand, in the Author's opinion, no convincing proof had as yet been given that the so-called "flaws," microscopic or visible, such as occurred in ordinary steel, had the importance sometimes attributed to them. Mr. Blount adduced the case of the difference of strength and ductility, longitudinally and transversely, in a rail, which he appeared to attribute to "gaps and crevices," distributed longitudinally, so that the rail "might be regarded as a bar built up of round rods of metal fairly well stuck together." In the Author's opinion the difference of longitudinal and transverse quality was far more probably explained by differences of general structure, differences of size and orientation of the crystalline and amorphous constituents, than by the assumption that it was due to flaws or crevices large enough to account for it.

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17 November, 1903.

Sir WILLIAM H. WHITE, K.C.B., D.Sc., LL.D., F.R.S., President, in the Chair.

The Discussion on Professor Unwin's Paper, "Tensile Tests of Mild Steel; and the Relation of Elongation to the Size of the Test-bar," occupied the evening.

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24 November, 1903.

Sir WILLIAM H. WHITE, K.C.B., D.Sc., LL.D., F.R.S., President, in the Chair.

(*Paper No. 3415.*)

"On the Distribution of Mean and Extreme Annual Rainfall over the British Isles."

By Hugh Robert Mill, D.Sc., LL.D.

Introductory.

The late Mr. G. J. Symons, F.R.S., prepared a map of the mean rainfall of the British Isles for his evidence before the Commission on River Pollution in 1868, based on the short period 1860–65.[1] Despite the small number of rainfall records available at that time, the map is so happily drawn that, until recently, it has practically been impossible to improve upon it. This was due partly to the fact that the mean rainfall for 1860–65 happened to coincide almost exactly with the true mean rainfall, but in greater measure to the skill with which Mr. Symons always grouped and discussed his data.

A rainfall map of the British Isles was prepared in 1884 by Dr. A. Buchan,[2] and based upon the period 1860–83, with numerous stations, of which, however, a very large proportion were necessarily computed from short periods. In 1895, Dr. Buchan published a series of maps of mean monthly and annual rainfall for Scotland,[3] for the period 1866–1890, and nearly one-half of the stations used for these had records extending over the whole 25 years. In 1899, Dr. Buchan published a series of rainfall maps of the British Isles[4], for the same 25-year period (1866–1890), reproducing for Scotland the maps published in 1895, and preparing those for England and Ireland from the data mainly compiled by Mr. Symons and published by the Meteorological Office for 1866–80, and for 1881–90. These maps are on a very small scale, on which it is possible to show only the bolder features of the distribution of rain.

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[1] Published in the Sixth Report of the Commission, p. 24.

[2] Journal Scottish Meteorological Soc., 3rd series, vol. vii. (1886) p. 131.

[3] *Ibid.*, vol. x. (1896) p. 3.

[4] Bartholomew's Physical Atlas, vol. iii. Meteorology. Westminster, 1899.

It is in no spirit of rivalry with the work of these authorities that the Author puts forward a new discussion of the mean rainfall of the British Isles. A large amount of new and trustworthy material is now available, and the time seems ripe for an effort to be made to lay down the larger details of the distribution of rainfall, by utilizing only the most carefully verified observations extending over a longer period than it was possible to secure at an earlier date. The credit for collecting and testing the observations on which this Paper is based belongs to Mr. Symons, whose work is the foundation of all that has been of value in the discussion of the rainfall of the British Isles, and whose memory, as an enthusiastic and irreproachably accurate scientific worker, should never be allowed to fade.

The late Mr. Symons and Mr. Sowerby Wallis brought together all the figures with which the Author deals, and published them year by year in the volumes of "British Rainfall." The original records are preserved by the Author in the office of the British Rainfall Organization; and to his former colleague, Mr. Sowerby Wallis, hearty thanks are due for constant advice and ungrudging help during the preparation of this Paper. The responsibility for the methods employed and the conclusions arrived at rests, however, upon the Author alone.

The mass of data, provided almost exclusively by the spontaneous labours of voluntary observers, and not least by the friendly help of many members of this Institution, is absolutely unique, and finds nothing to approach it in the records of other countries.

Length of Period Required for Mean Values.

The discussion of mean rainfall by Sir Alexander Binnie in 1892,[1] established the necessity of taking a long period in order to obtain an approximation to the true average value, and his conclusion was that at least 30 or 35 years were necessary for this purpose. That Paper dealt specially with 97 years, or rather more than one-half, of the long record maintained at Padua: and this in its entirety, together with the somewhat shorter records at Milan and Klagenfurt, has recently been subjected to exhaustive discussion[2] by Professor J. Hann, of Vienna. The result of his discussion is to give the follow-

[1] Minutes of Proceedings Inst. C.E., vol. cix., p. 89.

[2] "Die Schwankungen der Niederschlagsmengen in grösseren Zeiträumen." Sitzungsber. der k. Akad. der Wissenschaften in Wien, Mathem.-naturwiss. Classe, vol. cxi. Part IIa. p. 67. Vienna, 1902.

ing values for the average departure of the mean annual rainfall for shorter periods from the mean of the whole period at each station.

——	5 Years.	10 Years.	20 Years.	30 Years.	40 Years.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Padua (176 years) . .	9·6	8·4	6·6	2·5	2·4
Klagenfurt (88 years) .	9·5	8·1	5·2	2·6	2·6
Milan (100 years) . .	7·0	5·9	3·9	2·7	2·0
Average . .	8·7	7·5	5·2	2·6	2·3

These figures deal with continental stations, but Table I. (p. 318) gives details of five stations in the British Isles for 70 years. The figures for each station express the rainfall as ratios, the mean for 70 years being taken as 100 in each case. The values for each year and for all the possible groups of 10, 20, 30 and 40 consecutive years are stated as in Professor Hann's Paper, not merely for groups of consecutive decades as in the Author's recent Paper in "British Rainfall."[1]

Considering deviations from the average, irrespective of sign, the following summary of Table I. exhibits substantial agreement with the continental figures, only indicating less extreme variations.

EXTREME AND AVERAGE VARIATION OF THE MEAN ANNUAL RAINFALL OF VARIOUS PERIODS FROM THE MEAN ANNUAL RAINFALL OF 70 YEARS EXPRESSED AS 100.

——	10 Years.		20 Years.		30 Years.		40 Years.	
	Extreme.	Average.	Extreme.	Average.	Extreme.	Average.	Extreme.	Average.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Chilgrove .	8·1	2·7	4·1	2·2	2·7	1·4	2·0	0·7
Nash Mills.	16·4	4·6	8·0	3·8	5·0	2·9	3·4	2·1
Orleton . .	17·4	5·5	11·0	4·2	7·8	3·7	6·1	3·1
Boston . .	19·4	6·3	8·4	3·9	4·0	1·9	3·0	1·2
Kendal . .	12·2	4·2	5·9	3·0	2·9	1·3	3·0	1·2
Average .	14·7	4·7	7·5	3·4	4·5	2·2	3·5	1·7

The maximum deviation of any period of 10 years from the 70 years' mean was 19·4 per cent. at Boston for 1874–83, which

[1] "The average rainfall of the decades 1880–89 and 1890–99." "British Rainfall," 1901, p. 15.

included the greatest run of very wet years on record. The greatest deviation from the average of any 30-year group was 7·8 per cent. at Orleton for the period 1857–86.

It appears from the Table that the mean annual rainfall deduced from 30 years' observations is not subject to much greater variability than that deduced from 40 years' observations, though it is true that the agreement of the 30 and 40 years' means is a little closer in the case of the continental than in that of the English stations. It seems reasonable to go a step beyond Sir Alexander Binnie, and say that 30 years are quite sufficient to yield a satisfactory mean annual rainfall if the limit of error may average 2 per cent. on either side of the true mean. The extreme variations show that an individual station may in one particular period of 30 years give a mean value differing by as much as 10 per cent.[1] from the mean of another particular period of 30 years.

Table I. (p. 318) shows that the averages of periods of 10 years often exhibit remarkable differences in different parts of the country, while the averages of successive periods of 30 years usually preserve similar ratios during the same group of years at all the stations considered. This may be interpreted as indicating that the local fluctuations, which in any one year make one part of the country exceptionally wet and another exceptionally dry, are not as a rule eliminated by taking the mean of 10 years, but are practically eliminated when a period of 30 years is considered. In other words, the longer the period under consideration, the more nearly normal is the space-relationship of the rainfall over the country.

The importance of securing as long a series of observations as possible for all the stations employed in establishing the average distribution of annual rainfall is fully recognized; and the foregoing considerations show that 30 years is the shortest time which may profitably be considered. A longer period would be a little better; but after 30 years any small increase of approximation to a true mean can only be obtained by a great extension of the duration of the record.

In order to get substantially better results than the 30 years' average, it would be necessary to take a 50 years' average, and the number of stations available with such a record is far too small to yield a satisfactory distribution.

On account of the difference which may exist between one period

[1] Maximum differences between any two periods of thirty years, Chilgrove 5·0, Nash Mills 8·7, Orleton 10·7, Boston 7·0, Kendal 3·9.

of 30 years and another, it is important to work with one and the same period for all stations, and to select a period the value of which is near the true mean of a much longer period. The ratios in Table I. supply a ready method of selecting the period which comes nearest to the true mean.

It is usual to handle the average values in groups of 10 years, not because there is any special virtue in a period of 10 years, but merely because 10 is a convenient and labour-saving number. Following the custom of Mr. Symons, from which it would now be difficult to depart, the decades may be considered as running from 0 to 9. Although it would be more suitable for some purposes, and arithmetically more consistent, to group the years into decades from 1 to 0, the limits selected do not make the least difference in the present case, and, like every arrangement which Mr. Symons made, the use of decades including all the seventies, eighties, etc., has great advantages for simple registration and ready reference. Expressing as in Table I. the value of the 70 years' mean rainfall at each station as 100, the values for the different 30-year groups of whole decades come out as follows:—

——	1830–59.	1840–69.	1850–79.	1860–89.	1870–99.
Chilgrove	99·5	98·5	100·1	100·7	101·1
Nash Mills	97·8	97·4	100·8	103·8	102·3
Orleton	97·1	99·5	105·3	106·9	101·7
Boston	99·3	98·8	97·4	103·5	101·9
Kendal	99·5	97·7	98·1	100·4	98·8
Average	98·6	98·4	100·3	103·1	101·2

This shows that the 30 years ending with 1879 is the nearest to the true mean; but the extreme difference between any two stations for that period is practically 8 per cent., showing an irregular distribution. The 30 years ending with 1899, on the other hand, although on the whole 1·2 per cent. above the true mean, shows an extreme difference between the ratio at any two stations (Nash Mills and Kendal) of only 3·5 per cent.

The distribution of rainfall is so much more uniform, that this period may be accepted as on the whole the most suitable to adopt. This conclusion is satisfactory for another reason; the number of stations yielding averages for the last 30 years, save one, of the nineteenth century, is far greater than that for any earlier period of equal length.

PRINCIPLE OF RAINFALL-MAPS.

The problem of determining the distribution of rainfall is that of preparing a rainfall-map, for which it is important to have very numerous stations well distributed over the country.

In drawing a map of average rainfall, meteorologists and physical geographers have had much to say[1] as to whether it is right to draw isohyetal lines strictly in accordance with the available figures, or whether it is permissible to draw in lines hypothetically where there are no figures, but where the height or configuration of the land, or the nature of the vegetation, indicate that certain limits of rainfall have probably been reached. This question need not be discussed at present, for it was one of the chief objects in undertaking this work to ascertain how far the distribution of rainfall, as expressed by actual observations, showed a relation to the configuration of the ground; and to have used any assumption as to that relation in drawing the lines would, of course, have defeated the object. Maps showing no physical features were accordingly used for plotting the figures, so that there was nothing but the figures themselves to suggest the run of the isohyetals. Hence the resulting maps are original and independent evidence from which the general relation of rainfall to physical or any other features may be worked out absolutely independently of theory. One or two doubtful places are specially referred to in the sequel; but over 95 per cent. of the whole area there is no reasonable doubt whatever as to how the lines ought to run.

It is not claimed that this is necessarily the most scientific method of attacking the problem; but it appears to the Author to be the best way to begin the attack by laying down a foundation of absolutely neutral fact, which can afterwards be compared with any theory, forming a standard by which theoretical conclusions may be tested. The perfect rainfall-map is still a thing of the future, and many preliminary studies are necessary before it can be drawn. Among these is the detailed investigation of the effects of local conditions in small areas.

Turning to the number of sets of observations kept for 30 years at one station with the gauge in the same position, which are available, it is found that there are 267 for England, 12 for Wales, 21 for Ireland, 80 for Scotland: in all 380 perfect 30-year records. This number is considerable, and, if the stations were distributed

[1] See a detailed discussion of this question in the *Monthly Weather Review* of the U.S. Weather Bureau for April, 1902.

uniformly over the country, it would be sufficient without any supplement to allow of a serviceable map being drawn on a small scale. But it was found on plotting the figures that in some districts, such as that within 50 miles of London, the records were very numerous, while in others, especially in the west of Ireland, in Mid-Wales, and in the Highlands of Scotland, they were scattered very thinly indeed. The next step was accordingly to take out the records of 20 years or more, within the period 1870–99, for 668 stations in the districts where perfect records for the 30 years were fewest; and to compute the equivalent values for 30 years by comparison with two or more neighbouring stations. This method is familiar to all who have had to do with the calculation of true mean falls, and it is so generally employed and so firmly established that it is unnecessary to dwell upon it further. When this process was completed there still remained a few large gaps, especially in Scotland and Ireland, and in order to fill these, stations having from 15 to 20 years of continuous records were used, their indications being reduced to their equivalents for 30 years by computation. It would have been possible to go much farther, and to produce a still better distribution of figures, by computing true means from shorter periods than fifteen years. If it had been a question of one small area there would have been no reason why this should not be done: but it was felt that, taking into account the distance of some of the points concerned from the stations of reference, it was better to avoid any chance of falling into error, even though the chance was not great. The reason for omitting stations which had not observations extending over at least half the period under discussion, was simply a desire to place the data used beyond criticism on the score of length of record. The rule was broken of necessity in a very few instances in the Highlands, and in Ireland; but of the districts in which it was necessary to do this the distribution of rainfall is recognized as less certain.

The accuracy of the individual records is a vital point, and the endeavour to work with so long a period as 30 years, during which the position of the gauge has remained the same, introduces two main sources of possible error. The more serious is the change which 30 years works in the surroundings of a rain-gauge, usually by the erection of buildings which obstruct or intensify the prevailing wind or by the growth of trees over-shadowing the gauge, and either sheltering it from rain or allowing more rain and condensed moisture to fall into it than it should receive. The second difficulty is that an observer who was in middle life when the 30 years began, had grown old before they ended, and so might read less accurately.

In order to detect and guard against these and the grosser errors and accidents to which all observers are liable, two methods were employed. The annual values used were those which had been published annually in "British Rainfall," and had thus been subjected to critical examination by Mr. Symons, and, if doubtful, had been referred to the observer and verified. When the site of a gauge had been changed or its height above ground greatly altered during the 30 years, the series was rejected altogether; or if the change were a temporary one affecting only one year, the value for that year was specially computed. The second and severer test consisted in placing all the mean values expressed to the nearest half inch on the map and critically comparing them. As a rule contiguous stations agreed so closely that any exceptional figure caught the eye at once, and could be enquired into and verified. The uniformity of the values, or the gradual manner in which they merged into each other, inspired the greatest confidence in the substantial accuracy of the observations, and speaks volumes for the conscientious labours of the individual observers.

The figures for England and Wales, which were most numerous, were plotted on a map on the scale of 16 miles to an inch, those of Scotland and Ireland on a map on the scale of 28 miles to an inch, and after the isohyetal lines were drawn they were all transferred to this smaller scale. Lines were drawn for each 5 inches of rainfall up to 40 inches, for each 10 inches up to 60 inches, and after that for each 20 inches.

For the whole of England, except perhaps for the small hill ranges in Shropshire, the Cheviots and the Yorkshire Wolds, the isohyetal lines may be trusted absolutely as showing the facts of the distribution of rainfall with as much accuracy as the scale of the map admits. In Scotland, the southern half of the country may be taken as satisfactory, but in the north-west Highlands and the remoter off-lying islands, the lines may have to be considerably shifted and modified when additional stations have been established, and sufficient time has elapsed to enable the true mean to be determined. The records for the outer Hebrides, and for Orkney and Shetland, are so deficient, and some of those that exist are so contradictory, that it was reluctantly decided not to extend the isohyetal lines over those islands. If full reliance could be placed upon the readings of all the gauges which the Commissioners of Northern Lighthouses have been so public-spirited as to establish all round the coast of Scotland, the result would be different: but partly from the necessarily exposed positions, partly from the

pattern of some of the older gauges, and partly it may be from other causes, the records of rainfall at some of the lighthouses have often had to be omitted from "British Rainfall" as unsatisfactory.

In Ireland the rainfall-stations are comparatively few: but the simpler configuration of the country allows of considerable reliance being placed on the isohyetal lines as far west as the Shannon. Along the extreme western border of the island, however, it is impossible to be so confident, and more stations in that region are urgently wanted.

The map of mean rainfall now put forward, does not at the first glance differ greatly from its predecessors. But it has at least the advantage of being founded upon a more homogeneous and longer series of observations than has ever been brought together previously. It has been drawn from these data alone, without reference to the maps published by Mr. Symons or Dr. Buchan, the general features of which it confirms, while it supplements them with more detailed information.

Mean Rainfall 1870–99.

The map of mean annual rainfall for the period 1870–99 (Fig. 1, Plate 2), shows no part of the British Isles with a less fall than 20 inches, although on the east coast, at Shoeburyness and Spurn Point, the value to the nearest half inch is 20 inches.

The driest areas, up to 25 inches, occur in three regions: (1) a narrow coast strip round the Moray Firth, probably in no place more than 5 miles wide, and only measuring 224 square miles, (2) a roughly triangular area round the Thames estuary, bounded by a line running from Reading to Chatham and Dover on the south, and by a line running from Reading to London and Yarmouth on the north-west, the whole with an area of nearly 3,400 square miles, and (3) a broad strip of country occupying the east of Central England from the Humber southward, and separated from the dry region of the Thames and Essex by a very narrow band, corresponding to the East Anglian Heights, in which the rainfall is appreciably higher. This area measures about 6,300 square miles. It is broken by a broad strip in central Lincoln, where a higher rainfall prevails over the Lincolnshire Wolds, and it does not extend into north-east Norfolk. A narrow strip with rainfall under 25 inches runs from Bedford westward through Northampton, Leamington and Evesham to Tewkesbury, parallel to and north of the Oolitic escarpment.

The range of rainfall from 25 to 30 inches extends over a greater area than any other, for it occupies more than one-third of the surface of England, an area of 18,500 square miles. It is convenient to look on this zone as representing the prevailing rainfall of England, and to define the limits of the wetter regions which intrude into it on all sides, except the east. The region of prevailing rainfall (25 to 30 inches) extends to the English Channel at Dover on the east, and between Southamptom Water and Poole Harbour in the centre, while it reaches the west coast in two narrow arms—one at the head of the Bristol Channel, the other between the Mersey and North Wales, both corresponding with gaps in the bordering chain of high land. A broad coast-strip runs north to Berwick-on-Tweed, and northward along the east of Scotland, about 5,300 square miles of the northern kingdom coming within this range.

In Ireland, only a patch round Dublin, with an area of 700 square miles, has a rainfall under 30 inches.

Rainfall above 30 inches prevails over practically the whole of Ireland, and all of Scotland, except the eastern seaboard and the lower valleys of the larger east-flowing rivers, such as the Dee, Tay, Forth and Tweed. In England it occurs in isolated patches which are of great interest because each one of them coincides with some marked feature of vertical relief, and it is impossible not to recognize that there is a definite connection between the amount of rainfall and the configuration.

The North-Western area with over 30 inches extends from the Scottish border as far south as Walsall, where it tapers to a point. It contains a total area of about 9,000 square miles. The eastern border runs in a slightly wavy line passing very near Wooler, Morpeth, Hexham, Durham, Ripon, Harrogate, Sheffield, Chesterfield, Derby and Burton. Taking it as a whole, this line includes the land over 500 feet—and many valleys penetrating it—as far south as Derby, after which it runs out over lower ground. On the west the area over 30 inches extends to the coast from the Solway, almost to the Mersey, where a distinct diminution of rainfall occurs apparently without reference to the height of the land. It may be said that, as a rule, on the eastern slope of the Pennine Highland a rainfall exceeding 30 inches is rarely found at elevations less than 400 feet, except in valleys running up between higher land.

In the North Riding a small patch of more than 30 inches occurs, on the Cleveland Hills and the North York Moors, and probably includes all the land in that region exceeding 1,000 feet

in elevation. In the East Riding another small patch with over 30 inches lies between Driffield and Pocklington on the Yorkshire Wolds, where the elevations exceed 500 feet.

The next area within the isohyetal of 30 inches, includes practically the whole of Wales and a broad strip of the border west of the valleys of the Dee and the upper Severn, about 8,500 square miles in all. South of the Clee Hills the line of 30 inches swings westward and keeps west of the Wye until, at Ross, it turns east again to surround the Forest of Dean.

Another area over 30 inches contains about 7,800 square miles, and includes the whole Devon-Cornwall peninsula with three prolongations eastward. One of these prolongations runs north-eastward to Chipping Norton along the Cotswold Hills; the second runs eastward to Newbury over the Marlborough Downs, while the third runs south-eastward and includes Salisbury Plain.

The general outlines of all these large areas are perfectly satisfactorily laid down, but the observing stations are often not close enough to define small details perfectly. Fortunately, however, the Wealden area occupied by the three counties of Kent, Surrey and Sussex is extremely rich in rain-records, and although the elevations are moderate, the configuration is very striking and the land-forms are sharply defined. Here accordingly it is possible to find some trustworthy evidence of the detailed as well as of the general distribution of rain, and here it is surprising to see how distinctly the lines of equal rainfall laid down on a featureless map trace out the lines of hill and plain.

The Wealden area over which more than 30 inches of rain falls, measures about 2,500 square miles. It extends eastward in a compact rectangle from Winchester and Southampton as far as Guildford and Horsham, and then forks into three branches separated by drier strips. The first branch runs along the line of the South Downs, extending not quite so far south as the coast, and it terminates at Hastings. To the north of it a drier strip runs eastward from Dungeness and the dead flat of Romney Marsh to Horsham, north of which the central branch runs east over the central Wealden Heights, as far as Cranbrook, while north of this a second dry tongue runs east from Dungeness along the plain of the Weald and apparently along the slope of the Lower Greensand escarpment as far as Red Hill. The third branch of high rainfall is very narrow, sweeping along the North Downs from Guildford to Dover, and it is possibly broken in two places—at the gaps in the ridge near Maidstone and Canterbury. Three small patches where the rainfall exceeds 35 inches occur north of the highest

land near Midhurst, near Crowborough and near Dover. The Author has already published a discussion of the rainfall of a small section of the South Downs,[1] and Mr. H. S. Eaton had previously treated of the distribution of rainfall over a considerable area of the North Downs.[2]

The fact that the maximum rainfall occurs beyond the crest of the hill on the leeward side is, of course, explained by the maximum condensation taking place when the air is raised to its greatest altitude immediately after crossing the divide. It is on a small scale a repetition of the phenomenon familiar at Seathwaite, and has long been fully known and understood by all who deal with rainfall.

In considering the areas with rainfall above 40 inches, it will be convenient to take the three kingdoms separately; and it may be useful to use the term wet areas for those districts in which the mean rainfall distinctly exceeds the average of the British Isles as a whole.

The Northern wet area of England measures about 3,500 square miles. It includes the whole of the Lake District, and to the south its western boundary runs close to the main line of the London and North Western Railway from Lancaster to Preston, then sweeps round past Bolton, Bury and Rochdale whence it runs SSE. to a point midway between Leek and Buxton. On the east the boundary of this wet area follows the Eden Valley and runs on to Askrigg and Pateley Bridge; here its course is inflected by a broad bay of lower rainfall extending up the valley of the Aire and reaching across the watershed to the valley of the Ribble. South of this interruption the western boundary runs south, a few miles to the west of Bradford, Halifax, Huddersfield and Sheffield and thence south by west to its termination.

The scientific interest of this wet area lies in the curious relation, and sometimes it would almost seem the want of relation, between the rainfall and the physical features. Its practical interest is well known to waterworks engineers, for from it all the great towns of the north of England—Liverpool excepted—derive their whole water-supply. It is very largely the observations kept up by the engineers in charge of the various waterworks, canals and railways of that part of the country, that make it possible to draw this important isohyetal of 40 inches with so considerable a degree of confidence. It must, however, be remembered

[1] In "A fragment of the Geography of England—South West Sussex," *Geographical Journal*, vol. xv. (1900), p. 206.

[2] Transactions of the Croydon Natural History Club, 1886.

that the configuration of this district is very complex, and that additional observations are still necessary in places where no rain-gauges have yet been fixed, before the minor inflexions of the line or its exact situation within a few miles can be accepted as quite certain. Speaking generally, it may be said that south of the Ribble-Aire depression scarcely any land over 1,000 feet in elevation has less than 40 inches of rain, and very little land under 750 feet in elevation has so much as 40 inches of rain, unless it may be on the floors of narrow valleys. North of the Ribble-Aire depression the most striking feature is that the grand escarpment of Crossfell which walls in the Eden Valley on the east, and the whole of the high ground to the east of it, although containing the greatest extent of land over 2,000 feet in elevation in England, appears to have less than 40 inches of rainfall. There is, indeed, a large area with more than 35 inches, and there is reason for believing that more complete observations will show a heavier fall in the district east of Cross Fell. In accordance with the principle adopted, no isohyetal higher than 35 inches is drawn in this area, but it must be pointed out that the actual rainfall over several hundred square miles within it very likely exceeds even 50 inches in amount, and a query is accordingly placed on the map. Of the relative dryness of the lower Eden valley and the Solway shore there can be no question.

The wet area of Wales, with a rainfall exceeding 40 inches, includes about 5,400 square miles. It occupies almost the whole of the principality except Anglesea, the extreme western promontories, and a very narrow strip of the north coast. On the east the boundary, marked by the line of 40 inches, runs, on the whole, parallel to the line of 30 inches, and except in two places where the parallelism breaks down it includes all the land above 1,000 feet in elevation. The larger of these exceptional districts lies partly in Montgomery and partly in Shropshire; the smaller and more elevated is the group of the Black Mountain, in which the counties of Brecon, Monmouth and Hereford meet. It is likely, however, that the rainfall of those hilly districts is higher than the map can show, for there are not sufficient observations in either neighbourhood.

The wet area of Cornwall and Devon occupies about 2,700 square miles of the peninsula. A narrow coast strip and the various promontories have less than 40 inches of rain, while on the east the wet area is sharply marked by the eastern slopes of Exmoor and Dartmoor. A small patch of over 40 inches occurs between Chard and Crewkerne, and a larger patch lies on the north-eastern part of the Mendip Hills. It is interesting to note that these

isolated wet patches are separated from the wet Devonshire moors by a broad belt with a rainfall below 35 inches, which runs between the mouth of the Exe and that of the Parret, and corresponds with a marked depression of the ground.

Before going on to Scotland and Ireland, it may be convenient to refer briefly to the regions of highest rainfall within the three great wet areas of England and Wales.

In the Northern wet area the line of 50 inches includes the whole Lake District, except a narrow coastal belt, and extends across the Shap Fells as far as Hawes on the east, Kirkby Lonsdale on the west, and the Ribble valley on the south. This is divided into two very wet portions, a small one in the north-west of Yorkshire at the head of the Ribble valley, where about 180 square miles have more than 60 inches of rain, and a larger one, measuring about 560 square miles, in the central Lake District. The average rainfall of the Lake District was dealt with very fully by Mr. Symons in 1898.[1]

On the scale of the present discussion, it is enough to say that all the large lakes, except Bassenthwaite Water and the lower part of Ullswater, lie wholly within an area having more than 60 inches of rain, that the streams entering the head of all the lakes, which radiate from a common centre,[2] lie wholly within an area with over 80 inches of rainfall, while about 64 square miles in the centre of dispersion of the waters, between Scafell and Helvellyn, have a rainfall exceeding 100 inches.

In the Northern wet area there may be several other small patches with over 50 inches (especially on the Cross Fell group), but the only one shown exceeding 50 square miles in area is that in the centre of the high ground which separates Blackburn and Accrington on the north from Bolton and Rochdale on the south.

In Wales the comparatively small number of rain-gauges makes it difficult to speak with certainty as to the exact limits of the very wet area. There can be no doubt, however, that the whole of the middle of Wales receives over 50 inches, from Bethesda on the north to Llantrissant on the south. It may very possibly be that the rainfall exceeds 60 inches continuously along the centre of the area over 50 inches, but following the records at present available it seems safer to represent this isohyetal as

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[1] "British Rainfall," 1897, p. 17.

[2] See the Author's Bathymetrical Survey of the English Lakes. *Geographical Journal* vol. vi. (1895) pp. 46 and 135. Also published separately, London, 1895

forming three rings. Within the southernmost on the mountains of Brecon and Glamorgan a patch of at least 50 square miles round Aberdare has a rainfall exceeding 80 inches, but in the deep-cut valleys radiating to south-west and south-east there are considerable local differences. Within the northernmost area there is a considerably larger patch with over 80 inches, and around Snowdon the area with rainfall exceeding 100 inches is probably as large as that in the Lake District.

The third large wet area—that of Cornwall and Devon—exhibits two very wet districts in close agreement with the configuration. In the north the whole of Exmoor seems to have more than 50 inches of rain, and it is not improbable that a station near the highest part of the moor would yield an average of over 60 inches. In the south more than 50 inches falls on Bodmin moor and Dartmoor, while the summit of each moor receives more than 60 inches over a considerable area. In the case of Dartmoor, individual stations might undoubtedly be found giving higher readings, possibly exceeding 90 inches.

The observations in the southern half of Scotland are fairly complete and well distributed; but in the northern half they are few, of short duration and deplorably far between, so that the isohyetal lines had to be drawn in a somewhat more generalized form than those of England. The general features are quite clear, and it appears that except in the south-west, and along the east coast, the lines of equal rainfall are determined rather by position with regard to the coast than by the configuration or elevation of the land. The line of 30 inches, as already described, shows a close relation to the form and height of the land. So does the line of 50 inches on the Galloway hills; but east of the valley of the Nith the very wet area is far from coinciding with the whole of the higher part of the Southern Uplands. From the Clyde estuary to Cape Wrath the whole west of Scotland has a very high rainfall, increasing from about 50 inches on the west coast and the western side of the Inner Hebrides to a maximum exceeding 80 inches along the meridian of 5° W. North of Loch Linnhe the wettest strip lies entirely west of the fifth meridian, south of Fort William it lies entirely to the east of it. The chief influence of the broad lowland valley between the Clyde and Forth seems to be the extension of the area of rainfall over 40 inches as far east as Dunfermline and Kinross, the isohyetal of 40 inches running thence to the west of north until it nearly reaches Cape Wrath. It scarcely gets east of the Highland Railway at any point. A similar extension of the area of over 40 inches of rain to the

Cheviots appears to be a consequence of the action of the valleys of the Solway Firth and the Tweed.

It is much to be regretted that there are so few observations in the great mass of high land east of the valleys of the Tay and Spey. Here there is the greatest and most uniform mass of land approaching and exceeding 3,000 feet to be found in the British Isles; yet so far as the records go none of it appears to receive a rainfall exceeding or even attaining 40 inches. It is difficult to believe that higher values would not be found if gauges were more generally distributed; yet it must be concluded that the rainfall here is very much less than in the north-western highlands; and in spite of its great height its remoteness from the west coast saves this part of the country from an excessive rainfall. Dr. Buchan carries the rainfall of 40 inches and over very much farther to the east than is warranted by the principle on which the map accompanying this Paper is constructed.

In Ireland, the distribution of rainfall is apparently very simple. The half of the island which lies west of the Shannon and the Foyle has a rainfall everywhere over 40 inches. In the south of Ireland the area over 40 inches covers, though not very exactly, the southern mountain ridges, and extends north-eastward close up to Dublin along the mountains of Waterford, Wexford and Wicklow. Equally heavy rainfall occurs on the Mourne Mountains and on the hills north of Belfast. In the rest of the north of Ireland there is no special relation to be seen between the isohyetals and the configuration, but observations are so scanty that this need excite no surprise. West of the Shannon the lines can be drawn only within wide limits of deviation; but it seems clear that falls exceeding 50 inches are confined to the west of Kerry, Galway and Mayo, while only two localities with over 60 inches are indicated, one in the extreme west of the Connemara country, the other about Killarney and the mountains which separate the deep inlets of the Kerry coast. There is reason to believe that an increased number of stations would reveal a somewhat more complex distribution of rainfall in the south of Ireland, and perhaps also in the north; but probably the greater part of the country would show simply the uniform and gradual diminution in wetness from west to east which is the distinguishing feature of Ireland as compared with Great Britain.

Having called attention to the few weak points in the map of average rainfall, it may be permissible to point out again that for by far the greater part of the British Isles, the observations are as close and trustworthy as is necessary for the scale on which this

discussion has been carried out; while (the Outer Hebrides, Orkney and Shetland being omitted from consideration) it may be confidently claimed that the small portion which is less satisfactorily determined is much more likely to be correctly than incorrectly charted. The map is believed to afford a more satisfactory basis for calculating the mean rainfall of the great divisions of the United Kingdom and of the British Isles as a whole than has been available before.

Had that course not been deliberately avoided, on account of reasons already stated, it would have been possible, by reference to the proved relations of rainfall, position, and configuration, to draw supplementary but hypothetical isohyetals that might more nearly represent the details of the distribution of rain; but this would hardly alter the relative areas at different intensities, and the Author believes it would make a scarcely perceptible difference in the mean values.

In the Author's opinion, it is hopeless to attempt to find any definite numerical relation between the amount of rainfall and mere height above sea-level that would be applicable to the whole country; but the foregoing discussion seems to show that for each particular district and exposure some relationship might be worked out between rainfall and configuration, which involves not only height, but the general form and exposure of the surface. This question, however, is reserved from the present discussion.

In order to arrive at the average rainfall of the country the areas between the successive isohyetal lines were measured, the average rainfall for each zone was estimated by examination of a map on which all the figures were placed, and the volume of the mean year's fall was calculated in units, which for convenience were taken as 1 square mile by 1 inch. The sum of these units divided by the total area measured gives the average rainfall of the country.

Table II. (p. 320) contains the figures in question calculated from seventy-five separately measured portions. The totals are as follows:—

Divisions.	Area. Square Miles.	Volume of Rain. Square miles × inches.	Average Rain. Inches.
England	50,058	1,582,925	31·62
Wales	7,376	365,320	49·53
Isle of Man	224	7,764	34·66
Scotland	27,413	1,284,211	46·85
Ireland	32,694	1,382,190	42·28
British Isles	117,760	4,622,410	39·25

The result is to give a mean rainfall for England of 32 inches, for Wales of 50 inches, for Scotland of 47 inches, for Ireland of 42 inches, and for the British Isles as a whole of 39 inches, the figures being given to the nearest inch.

As a matter of pure curiosity the rules applicable to small areas may be supposed to apply to the country as a whole; then the average rainfall of 39 inches diminished by 20 per cent. would correspond to 31 inches as the mean for the three driest consecutive years, and, assuming the evaporation at 14 inches, this would leave 17 inches of rainfall, which over 120,000 square miles would amount in round numbers to 81,000,000,000 gallons per day. At the rate of 25 gallons per head per day this would suffice for a population of more than 3200,000,000 or twice the actual population of the whole world.

Taking the population of the British Isles at 40,000,000 in round numbers, or one-fortieth of the population of the world, it is seen that only half an inch of rain over the whole surface would suffice for a liberal water-supply, could it but be fully utilized. As no exact figures are at present available for the average height above sea-level of the British Isles, though the levellings of the Ordnance Survey supply all the data, it is impossible to translate this vast quantity of water into its equivalent horse-power.

With regard to the relative amounts of rainfall in the different divisions of the United Kingdom, it should be remembered that whereas England at present contains 72 per cent. of the population of the United Kingdom, it receives only 36 per cent. of the volume of rainwater which annually falls upon the British Isles.

THE WETTEST AND THE DRIEST YEAR, 1870–99.

The extremes of annual rainfall are no less important than the mean, but their investigation is more difficult. It very rarely happens that the rainfall at all stations in any division of the British Isles is over or under the average to the same amount at the same time. In other words, it is impossible to select any year of abnormally high or low rainfall in which all the stations are at their maximum or their minimum value respectively. The question was first investigated in a preliminary manner by considering a certain number of stations distributed uniformly over the country. The number was decided by a process of weeding out the more thickly-placed stations having a long record until they were approximately uniformly spaced all over the map. In all 291 stations were thus selected, and the figures for them are given

in Table III. (pp. 322–342), and the positions marked on the map, Fig. 4, Plate 3. Table III. gives the county, the name of the station, the height of the receiving surface of the gauge above the ground and above sea-level, the heaviest and the lightest annual falls recorded in the 30 years 1870–99, with the year in which each occurred, and the mean annual fall for the whole period. The mean values are placed within brackets if 5 years or more have been computed. The extreme values are placed within brackets if any part of any month is computed.

If the distribution had been absolutely uniform there would have been one station for every 400 square miles of surface; in other words, the stations would have been approximately 20 miles apart. But the actual numbers were for England 138 stations, or one to every 360 square miles; for Wales 21 stations, or one to every 360 square miles; for Scotland 79 stations, or one to every 370 square miles; and for Ireland 52 stations, or one to every 620 miles.

If the stations were numerous enough, the average of the whole number of values should be identical with the average calculated by measuring the areas on the map, supposing the latter to be correctly worked. The result of the comparison was as follows, taking the values to the nearest half inch:—

MEAN RAINFALL (1870–99).

——	England.	Wales.	Scotland.	Ireland.	British Isles.
	Inches.	Inches.	Inches.	Inches.	Inches.
From map	31·5	49·5	47·0	42·5	39·5
From stations	33·0	46·5	45·5	42·0	39·0
Difference . . .	+1·5	−3·0	−1·5	−0·5	−0·5

The results for Ireland and the British Isles are practically identical by both methods; for England the selected stations gave a rainfall 1·5 inch in excess of the average calculated by the map; for Scotland 1·5 inch lower; and for Wales about 3 inches lower. The discrepancy in the last case is easily explained by the relatively small number of stations in the wettest districts, and the undue prominence consequently given to the stations of low rainfall.

The years of maximum and minimum rainfall at the 291 stations were next extracted, and the cases where the 30 years were not quite complete were omitted. It at once became apparent that at a majority of stations the wettest year had been 1872, and the driest 1887. The actual figures for the number of stations at which a particular year was the wettest or driest of the thirty are as follows:—

—	Wettest Year.					Driest Year.					
	1872	1877	1882	1899	15 other Years.	1887	1870	1893	1898	1874	19 other Years.
England	92	12	9	..	12	53	25	8	14	9	17
Wales	11	2	2	..	..	7	1	2	..	..	5
Scotland	25	17	2	4	11	16	14	3	..	..	26
Ireland	17	3	..	..	5	16	1	3	..	..	5
British Isles . . .	145	34	13	4	28	92	41	16	14	9	53

This statement means that out of 125 stations in England the wettest year at 92 was 1872; the wettest year at 12 was 1877; at 9 it was 1882; and at 12 other stations the maximum annual rainfall occurred in some other year, and similarly for the other divisions. The maps (Figs. 5 and 6, Plate 3) show how in one district one of those years was the wettest over a considerable area, while in another district a different year was the wettest, and the same thing is even more strongly marked in the case of the dry years.

If it were found that no very great difference existed between the figures for 1872, and those for the wettest year, whatever it might be, or between the figures for 1887 and those of the driest year, whatever it might be, those two years could be used for investigating the relationship between the distribution of extreme and average rainfall. The following Table shows the result of such a comparison. In compiling it the numbers were made strictly comparable by computing the values of missing years in cases where the record was not complete for the whole thirty, by reference to surrounding stations for the years in question.

Average Rainfall calculated from 291 well-distributed Stations.

—	Number of Stations.	Maximum Years.	Year 1872.	Min'mum Year.	Year 1887.
		Inches.	Inches.	Inches.	Inches.
England	138	46·98	46·48	22·83	23·97
Wales	21	68·60	68·30	32·98	33·23
Scotland	79	67·12	60·25	32·25	37·64
Ireland	53	56·33	54·20	29·50	31·03
British Isles	291	56·01	53·20	27·57	29·68

It thus appears that for England and Wales the years 1872 and 1887 came within 1 inch of the values for the extreme rainfalls of any year, and for Ireland nearly within 2 inches, but for Scotland the similarity is not so close. There 1872 was proportionally drier, and 1887 proportionally wetter than in the other divisions, the average of the maximum years being nearly 7 inches wetter than 1872, and the average of the minimum years more than 5 inches drier than 1887, although no other years in the thirty came so near the extremes as did those two. Even taking this considerable difference into account, the extremes for the British Isles, as a whole, are within 3 inches of the value for the two selected years. The climatic contrast between the east and west of Scotland is so marked that it seems doubtful whether all parts of that country would ever have their maximum or minimum rainfall simultaneously; and, taken as a whole, it seems not unlikely that 1872 and 1887 are as extreme years as are ever likely to occur over the whole of the British Isles. Perhaps 1852 was as wet as 1872, and 1864 may have been as dry as 1887; but with these possible exceptions no other year of the nineteenth century approached either as an extreme.

Rainfall-maps were prepared for 1872 and 1887 (Figs. 2 and 3, Plate 2), utilizing all the values published in the volumes of "British Rainfall" for those years. Isohyetal lines were drawn, and the areas and mean fall were calculated exactly as for the general map. The results are given in Tables V. and VI. (p. 333). Table V. gives for comparison the same data for the map of the period 1870–99. As the isohyetal lines sometimes extend over a small portion of sea along the coast, the total areas as calculated in the three cases do not agree to 1 square mile: the difference, however, does not affect the averages.

Compared with the results of taking the mean of 291 well-distributed stations, the values calculated from the maps confirm the conclusion pointed out by the averages for 1870–99, namely, that the stations selected give slightly too much weight to the districts of heavier fall in England, and too much weight to the districts of lighter fall in Wales and Scotland. The fact that Ireland gives the same value by both methods of calculation, even although the number of stations is relatively smaller than for the other divisions, is to be explained by the more open nature of the country and the absence of any continuous highlands.

The following Table gives to the nearest half-inch a comparison of the results by the two methods:—

—	Average Rainfall. 1870–99.	Rainfall. 1872.	Rainfall. 1887.	Mean Diff.
	Inches.	Inches.	Inches.	
England, by map	31·5	45·0	23·5	..
" " stations . . .	33·0	46·5	24·0	..
" difference	+1·5	+1·5	+0·5	+ 0
Wales, by map	49·5	74·0	36·5	..
" " stations	46·5	68·5	33·0	..
" difference	−3·0	−5·5	−3·5	−4·0
Scotland, by map	47·0	62·5	39·5	..
" " stations . . .	45·5	60·0	37·5	..
" difference	−1·5	−2·5	−2·0	−2·0
Ireland, by map	42·5	52·0	32·0	..
" " stations	42·0	54·0	31·0	..
" difference	−0·5	+2·0	−1·0	0·0
British Isles, by map . . .	39·5	53·0	30·5	..
" " " stations . .	39·0	53·0	29·5	..
" " difference. . .	−0·5	0·0	−1·0	−0·5

Applying these differences as corrections to the extreme years, the mean and extreme annual rainfall of the British Isles is shown in the following Table, accompanied by the 30 years' average annual rainfall and the rainfalls of 1872 and 1887, calculated from the maps:—

—	Quantity to nearest Half-Inch.					Ratios.				
	Average.	Maximum.	1872.	Minimum	1887.	Average.	Maximum.	1872.	Minimum	1887
	Inches.	Inches.	Ins.	Inches.	Ins.					
England	31·5	46·0	45·0	22·0	23·5	100	146	143	70	74
Wales .	49·5	72·5	74·0	37·0	36·5	100	147	149	75	74
Scotland	47·0	69·0	62·5	34·0	39·5	100	147	133	72	84
Ireland	42·5	56·5	52·0	29·5	32·0	100	133	124	69	76
British Isles.	39·5	56·5	53·0	28·0	30·5	100	143	134	71	77

The maximum and minimum values for Wales as corrected, come out on the wrong side, but they may be taken as practically identical with those for 1872 and 1887 respectively. All the other values appear reasonable, and the general result is to show that over the British Isles, as a whole, the rainfall for 1872 was 3·5

inches lower than it would have been if all the stations had had their maximum annual fall in that year; while the rainfall for 1887 was 2·5 inches greater than it would have been if all the stations had had their minimum annual fall in that year. But on account of the improbability of all the maxima or all the minima occurring in any one year, it is safe to accept 1872 and 1887 as representative respectively of the wettest and the driest year likely to be experienced over the British Isles. For England and Wales the rainfall of 1872 was respectively 43 and 49 per cent. above the average, and that of 1887 was 26 per cent. below it, the amount of rain which fell in 1872 being very nearly twice as great as that which fell in 1887; for Scotland the excess in 1872 was only 33 per cent., and the defect in 1887 just 16 per cent; while for Ireland the excess in 1872 was 24 per cent., and the deficiency in 1887 was also 24 per cent., the difference from the average being the same for the two years, though on opposite sides. For the country, as a whole, the excess in 1872 was 34 per cent. or one-third; the defect in 1887 was 23 per cent., or not quite a quarter of the average fall.

These facts are more clearly presented in the following Table, which shows by ratios the excess and defect of the extreme years compared with the mean, and the difference between the two extreme years.

RATIOS OF AVERAGE RAINFALL CALCULATED FROM MAPS.

——	Mean. 1870–99	1872.	1887.	Difference 1872 – Mean.	Difference Mean – 1887.	Difference 1872 – 1887.
England . . .	100	143	74	43	26	69
Wales	100	149	74	49	26	75
Scotland . . .	100	133	84	33	16	49
Ireland . . .	100	124	76	24	24	48
British Isles . .	100	134	77	34	23	57

Mr. Symons in "British Rainfall, 1872," estimated the excess of rainfall in that year as 36 per cent over the British Isles, as a whole, taking the average of 90 well-distributed stations as a basis, and the mean of 1860–65 for comparison. The result now given, depending on an average calculated from over 1,000 stations and compared with a mean of 30 years, 1870–99, is a very striking confirmation of the earlier work. In 1887 the average deficiency was calculated by Mr. Symons by four different methods, which

gave respectively 31, 31, 30 and 27 per cent., the last value coming within 4 per cent. of that now arrived at.

Comparison of the three maps showing the average and extreme annual falls, shows at once their remarkable similarity as regards the position and form of the isohyetal lines: indicating that the conditions which operate in an average year to determine the distribution of the rainfall act also in the years of extreme drought and flood. Thus the line of 40 inches in 1872 and that of 20 inches—or in places 25 inches—in 1887, correspond generally with the position of the line of 30 inches in an average year, running close along the eastern sea-board of Scotland and marking out the North-Western, Welsh, South-Western and Wealden districts of high rainfall farther south, with outlying patches on the North York moors and wolds, the Lincoln wolds and Norfolk. In 1887, while all the rest of the British Isles showed a great reduction of rainfall, the west of Scotland had nearly its normal amount and distribution, so far as can be estimated. The area in the east Midlands, which has less than 25 inches in an average year, was the site of the somewhat smaller area under 15 inches in 1887, and was included in the somewhat larger area under 35 inches in 1872.

Table III. and Table IV. (p. 333) give the areas of the whole country in square miles for the average and extreme years; and, so far as regards England, where the data are most exact, they are reproduced in abstract in the following summary:—

Areas in Square Miles within Successive Rainfall Zones (England).

Year.	<15	15–20	20–25	25–30	30–35	35–40	40–50	50–60	60–80	80–100	>100
1887	1888	14,240	19,936	8,552	3,222	1,104	904	192	80	64	..
Average year	..	..	9,776	18,552	10,885	4,448	4,240	1,384	576	128	64
1872	..	..	..	1,884	8,944	10,178	16,532	7,936	3,606	730	232

Areas in Percentage of whole Area within Successive Rainfall Zones (England).

Year.	<15	15–20	20–25	25–30	30–35	35–40	40–50	50–60	60–80	80–100	>100
1887	3·8	28·4	39·7	17·0	6·4	2·2	1·8	0·4	0·2	0·1	..
Average year	..	..	19·5	37·0	21·7	8·9	8·5	2·8	1·2	0·3	0·1
1872	..	..	..	3·8	17·8	20·3	33·0	15·9	7·2	1·5	0·5

The Tables show that in an average year about 57 per cent. of the surface of England, or considerably more than one-half, has a

rainfall between 20 and 30 inches: in the driest year the same proportion lay between the same limits; but in the average year 31 per cent. of the area enjoys a rainfall of between 30 and 40 inches; while in the driest year 32 per cent. of the surface had less than 20 inches. Taking it in another way, in the driest year 89 per cent. of the surface of England had less than 30 inches of rain. In an average year 87 per cent. of the surface has more than 20 inches but less than 40 inches; and in the wettest year 87 per cent. of the surface had more than 30 inches but less than 60 inches of rain.

Again, from the point of view of the wettest and driest parts of the country an average year finds 4½ per cent. of the surface of England with more than 50 inches of rain. In 1887 there was not so much as 1 per cent. equally favoured; while in 1872 there was more than 25 per cent., or a quarter of the country. In an average year there is nearly 20 per cent., or one-fifth, of England with a rainfall smaller than 25 inches. In 1872 not a single rain-gauge recorded so little; while in 1887 72 per cent., or nearly three-quarters, of the surface received no more.

The Paper is accompanied by six maps, from which Plates 2 and 3 have been prepared.

[TABLES.

TABLE I.—VARIATION OF THE MEAN RAINFALL OF GROUPS OF YEARS FROM THE MEAN OF 70 YEARS AT FIVE STATIONS IN ENGLAND.

(The percentage variation of the mean of each group of 10 (20, 30, etc.) consecutive years from the mean of the 70 years 1830–99 is placed against the last year of the group.)

Years.	Chilgrove.				Nash Mills.				Orleton.				Boston.				Kendal.			
	10 Yrs.	20 Yrs.	30 Yrs.	40 Yrs.	10 Yrs.	20 Yrs.	30 Yrs.	40 Yrs.	10 Yrs.	20 Yrs.	30 Yrs.	40 Yrs.	10 Yrs.	20 Yrs.	30 Yrs.	10 Yrs.	10 Yrs.	20 Yrs.	30 Yrs.	40 Yrs.
1839	2·2	..	..	..	−0·5	..	..	..	−2·7	..	..	..	−1·0	..	..	..	10·3	–	..	..
1840	0·0	..	..	..	−3·0	..	..	..	−3·8	..	..	..	−4·1	..	..	..	8·4	..	..	..
1841	1·0	..	..	..	−2·7	..	..	..	−2·2	..	..	..	−3·3	..	..	..	6·9	..	..	..
1842	1·3	..	..	..	−2·3	..	..	..	−2·5	..	..	..	−2·2	..	..	..	6·6	..	..	..
1843	1·5	..	..	..	−2·7	..	..	..	−2·3	..	..	..	−1·4	..	..	..	6·8	..	..	..
1844	0·2	..	..	..	−2·0	..	..	..	−4·6	..	..	..	1·6	..	..	..	2·4	..	..	..
1845	0·2	..	..	..	−3·4	..	..	..	−4·6	..	..	..	2·7	..	..	..	1·8	..	..	..
1846	−1·7	..	..	..	−5·1	..	..	..	−5·1	..	..	..	3·7	..	..	..	−0·5	..	..	..
1847	−2·0	..	..	..	−4·3	..	..	..	−5·3	..	..	..	3·9	..	..	..	0·3	..	..	..
1848	2·4	..	..	..	−1·9	..	..	..	−1·1	..	..	..	9·5	..	..	..	2·4	..	..	..
1849	0·0	1·1	..	..	−4·4	−2·4	..	..	−3·6	−3·2	..	..	7·7	3·8	..	..	0·4	5·4	..	..
1850	1·0	0·5	..	..	−4·7	−3·9	..	..	−4·1	−3·9	..	..	8·4	2·2	..	..	0·6	4·5	..	..
1851	−4·3	−1·6	..	..	−8·4	−5·5	..	..	−7·1	−4·7	..	..	6·4	1·5	..	..	−0·7	3·1	..	..
1852	2·0	1·6	..	..	−3·0	−2·7	..	..	−0·5	−1·5	..	..	6·5	2·2	..	..	2·8	4·7	..	..
1853	3·1	2·3	..	..	−2·1	−2·4	..	..	−0·5	−1·4	..	..	5·3	1·9	..	..	−0·6	3·1	..	..
1854	1·1	0·7	..	..	−4·0	−3·0	..	..	−0·9	−2·7	..	..	2·0	1·8	..	..	0·0	1·2	..	..
1855	0·5	0·3	..	..	−3·4	−3·4	..	..	−0·6	−2·6	..	..	0·4	1·6	..	..	−3·7	−1·0	..	..
1856	0·0	−0·8	..	..	−3·3	−4·2	..	..	1·0	−2·1	..	..	−1·5	1·1	..	..	−6·3	−3·4	..	..
1857	1·7	−0·2	..	..	−1·4	−2·8	..	..	1·4	−1·9	..	..	−1·8	1·0	..	..	−9·0	−4·3	..	..
1858	−4·2	−0·9	..	..	−4·7	−3·3	..	..	−2·3	−1·7	..	..	−7·8	1·1	..	..	−12·2	−4·9	..	..
1859	−3·6	−1·8	−0·5	..	−1·7	−3·1	−2·2	..	−2·4	−3·0	−2·9	..	−8·7	−0·5	−0·7	..	−12·1	−5·9	−0·5	..
1860	−0·7	0·2	0·1	..	3·4	−0·6	−1·4	..	1·8	−1·2	−2·0	..	−4·2	2·1	−0·0	..	−10·6	−5·0	−0·5	..
1861	0·1	−2·1	−1·1	..	3·1	−2·7	−2·7	..	3·9	−1·6	−1·8	..	−5·2	0·6	−0·7	..	−7·9	−4·3	−0·6	..
1862	−5·5	−1·8	−0·7	..	−1·8	−2·4	−2·4	..	0·3	−0·1	−0·9	..	−7·6	0·5	−1·1	..	−10·1	−3·6	−0·2	..
1863	−7·9	−2·4	−1·1	..	−4·1	−3·1	−3·0	..	−0·5	−0·5	−1·1	..	−8·9	−1·8	−1·7	..	−7·0	−3·8	−0·3	..
1864	−7·1	−3·0	−1·9	..	−4·6	−4·3	−3.5	..	−0·2	−0·5	−1·9	..	−8·3	−3·2	−1·6	..	−6·7	−3·4	−1·4	..
1865	−4·2	−1·8	−1·2	..	−3·0	−3·2	−3.3	..	0·4	−0·1	−1·6	..	−6·7	−3·1	−1·2	..	−5·0	−4·3	−2·3	..
1866	−3·1	−1·6	−1·6	..	−1·7	−2·5	−3·4	..	1·4	1·2	−0·9	..	−4·7	−3·1	−0·8	..	−0·8	−3·6	−2·5	..

1867	−3·7	−1·0	−1·8	..	−2·6	−2·0	−2·8	..	1·5	1·4	−0·8	..	−5·4	−3·6	−1·1	..	1·0	−4·0	−2·6	..
1868	−0·5	−2·3	−0·8	..	−0·1	−2·4	−2·2	..	2·4	0·1	−0·8	..	−4·4	−5·9	−0·7	..	3·4	−4·4	−2·1	..
1869	−0·9	2·3	−1·5	−0·6	−1·8	−1·7	−2·6	−2·1	4·0	1·2	−0·4	−1·0	−2·7	−5·7	−1·2	−1·2	4·8	−3·6	−2·3	0·8
1870	−5·2	2·9	−1·6	−1·2	−6·5	−1·6	−2·6	−2·7	0·6	1·2	−0·6	−1·4	−8·8	−6·5	−1·5	−2·2	2·0	−4·3	−2·7	0·1
1871	−3·8	1·9	−2·7	−1·7	−5·7	−1·3	−3·7	−3·4	1·5	2·7	−0·6	−1·0	−8·3	−6·7	−2·4	−2·6	−0·1	−4·0	−2·9	−0·4
1872	−0·5	−3·0	−1·3	−0·7	−2·5	−2·1	−2·4	−2·4	4·8	2·6	1·5	0·5	−4·2	−5·9	−1·8	−1·9	2·9	−3·6	−1·5	0·5
1873	−0·3	−4·1	−1·7	−0·9	−2·1	−3·1	−2·7	−2·7	4 1	1·8	1·0	0·2	−3·9	−6·4	−2·5	−2·2	1·8	−2·6	−1·9	0·3
1874	1·0	−3·0	−1·7	−1·2	−0·4	−2·5	−3·0	−2·8	5·7	2·7	1·5	0·0	−2·7	−5·5	−3·0	−1·9	3·3	−1·7	−1·1	−0·3
1875	0·1	−2·1	−1·2	−0·9	−0·7	−1·9	−2·4	−2·6	8·2	4·3	2·7	0·9	−2·2	−4·5	−2·8	−1·4	4·0	−0·5	−1·6	−0·7
1876	−0·3	−1·7	−1·1	−1·3	0·4	−0·6	−1·5	−2·4	8·7	5·1	3·7	1·5	0·1	−7·3	−2·0	−0·6	2·3	0·7	−1·6	−1·3
1877	4·4	0·4	0·8	0·1	2·8	0·1	−0·4	−1·4	10·1	5·8	4·3	1·9	1·3	−2·0	−2·0	−0·5	5·9	3·5	−0·7	−0·4
1878	3·6	1·5	−0·4	0·3	8·8	1·8	−0·3	−0·7	13·1	7·8	4·4	3·0	3·0	−0·7	−2·9	0·2	4·1	3·7	−1·6	−0·6
1879	4·7	1·9	0·1	0·1	6·0	2·1	0·8	−0·5	13·4	9·1	5·3	3·1	13·5	0·4	−2·6	−0·1	1·6	3·2	−1·9	−1·3
1880	7·8	1·3	0·6	0·7	10·5	2·0	2·5	0·7	17·4	9·0	6·6	3·9	11·2	1·2	−0·6	1·7	2·0	2·0	−2·2	−1·5
1881	8·1	2·1	1·5	0·0	13·5	3·9	3·6	0·6	15·6	8·5	7·0	3·5	13·3	2·5	−0·1	1·5	3·8	1·9	−1·4	−1·2
1882	5·9	2·7	0·0	0·5	13·0	5·3	2·9	1·4	14·2	9·5	6·4	4·7	13·7	4·8	0·6	2·1	1·8	2·3	−1·8	−0·7
1883	6·4	3·1	−0·6	0·3	15·2	6·5	3·0	1·7	15·9	10·0	6·5	4·7	19·4	7·7	2·2	3·0	2·2	2·0	−1·0	−0·9
1884	5·6	3·3	−0·2	0·1	15·6	7·6	3·5	1·7	15·7	10·7	7·1	5·1	18·7	8·0	2·6	2·4	0·1	1·7	−1·1	−0·8
1885	5·0	1·5	0·3	0·4	16·4	7·9	4·2	2·3	13·5	10·9	7·4	5·4	17·8	7·8	3·0	2·3	0·0	2·0	−0·3	−1·2
1886	6·0	2·9	0·9	0·6	14·9	7·6	4·5	2·6	13·3	11·0	7·8	6·1	16·7	8·4	4·0	2·7	1·4	1·9	1·0	−0·8
1887	0·0	2·2	0·2	0·6	10·4	6·6	3·5	2·3	9·1	9·6	6·9	5·5	12·3	6·8	2·7	1·6	−5·2	0·3	0·6	−1·8
1888	0·6	2·1	1·2	−0·1	9·5	6·7	4·4	2·1	5·5	9·3	7·0	4·7	11·0	7·0	3·2	0·6	−5·3	−0·6	0·7	−2·5
1889	−1·7	1·5	0·7	−0·4	7·1	6·5	3·8	2·4	2·4	7·9	6·9	4·6	9·8	6·7	3·5	0·5	−5·3	−1·8	0·4	−2·8
1890	−4·3	1·7	−0·6	−0·6	2·6	6·6	2·2	2·5	− 1·8	7·8	5·4	4·5	1·7	6·4	1·4	0·0	−4·7	−1·4	−0·2	−2·8
1891	−2·0	3·1	0·8	0·6	2·6	8·0	3·5	3·4	− 0·1	7·7	5·7	5·2	0·4	6·9	1·8	0·0	−5·8	−1·0	−0·7	−2·5
1892	−4·5	0·7	0·3	−1·1	−0·9	6·1	3·2	1·9	− 5·3	4·5	4·6	3·5	−2·8	5·4	2·2	−0·2	−6·6	−2·4	−0·6	−3·0
1893	−6·8	0·0	−0·1	−2·0	−3·5	5·8	3·2	1·4	− 7·4	4·2	4·2	3·0	−9·0	5·2	2·2	−0·6	−7·7	−2·7	−1·2	−2·7
1894	−1·1	2·3	1·8	−0·4	−0·3	7·7	5·0	2·6	− 5·2	5·3	5·4	4·0	−6·7	6·0	3·1	0·3	−5·8	−2·9	−0·8	−2·3
1895	−0·6	2·2	1·5	0·1	−2·5	6·9	4·4	2·6	− 7·3	3·1	4·8	3·7	−7·0	5·4	2·9	0·5	−5·4	−2·7	−0·5	−1·6
1896	−1·4	2·3	1·4	0·3	−3·4	5·8	4·0	2·5	−11·9	0·7	3·4	2·9	−9·7	3·5	2·4	0·6	−7·6	−3·1	−1·3	−1·2
1897	2·4	1·2	2·3	0·8	−2·2	4·1	3·7	2·1	− 9·2	−0·1	3·3	2·9	−5·4	3·5	2·7	0·7	−3·2	−4·2	−0·8	−0·4
1898	0·3	0·4	1·5	1·0	−6·1	1·7	2·4	1·8	−11·5	−3·0	2·4	2·4	−6·4	2·3	2·5	0·8	−1·2	−3·2	−0·8	0·3
1899	0·4	−0·6	1·1	0·6	−6·2	0·4	2·3	1·3	−10·6	−4·1	1·7	2·5	−7·6	1·1	1·9	0·7	0·1	−2·6	−1·2	0·3
Average	±2·7	±2·2	±1·4	±0·7	±4·6	±3·8	±2·9	±2·1	± 5·5	±4·2	±3·7	±3·1	±6·8	±3·9	±1·9	±1·2	±4·2	±3·0	±1·3	±1·2

TABLE II.—CALCULATION OF THE AVERAGE RAINFALL OF THE BRITISH ISLES BY MEASUREMENT OF AREAS OF THE DIFFERENT ZONES OF RAINFALL ON THE MAP FOR THE PERIOD 1870–99.

Range.	Position.	Area.	Average Rainfall.	Volume of Rainfall. Square miles × Inches.
Inches.	*England.*	Sq. Miles.	Inches.	
<25	Hartlepool	64	24·5	1,568
,,	Colchester	3,392	24	81,408
,,	Lincoln, Cambridge	6,320	23·5	148,520
>25	Ongar	112	27	3,024
25-30	.. .. ..	18,440	27·5	507,100
>30	Battersby, Yorks.	192	33	6,336
,,	Pocklington	160	32	5,120
,,	Towcester	48	30·5	1,464
30-35	N.W. District	4,000	32·5	130,000
,,	Welsh Border	1,205	33	39,765
,,	S.W. District	3,200	32·5	104,000
,,	Brighton	2,080	32·5	67,600
>35	Alston	416	37	15,392
,,	Kidderminster	64	36	2,304
,,	Midhurst	176	36	6,336
,,	Grinstead	96	35·5	3,408
,,	Hassocks	56	35·5	1,988
,,	Ashford	72	37	2,664
35-40	Scottish Border.	320	37·5	12,000
,,	N.W. District	1,360	37·5	51,000
,,	S.W. District	912	37	33,744
,,	Bristol	368	37·5	13,800
,,	Dorchester	608	37·5	22,800
>40	Axbridge	112	43	4,816
,,	Chard	48	41	1,968
40–50	Scottish Border.	160	45	7,200
,,	N.W. District	2,000	45·5	91,000
,,	Lydney	64	41	2,624
,,	Cornwall	1,856	44	81,664
>50	Blackburn	56	55	3,080
,,	Barnstaple	176	53	9,328
,,	Staleybridge	16	52	832
50–60	Kendal	720	55	39,600
,,	Liskeard.	416	54	22,464
>60	Ribblehead	176	63	11,088
,,	Moreton Hampstead	144	70	10,080
,,	Launceston	64	61	3,904
60–80	Windermere.	192	70	13,440
80–100	Ambleside	128	87	11,136
>100	Seathwaite	64	115	7,360
	Total	50,053	—	1,582,925

TABLE II.—*continued.*

Range.	Position.	Area.	Average Rainfall.	Volume of Rain. Square miles × inches.
Inches.	*Wales.*	Sq. miles	Inches.	
25–30	.. ..	128	28	3,584
30–35	.. ..	528	32·5	17,160
35–40	.. ..	1,328	37·5	49,800
40–50	.. ..	2,592	45	116,640
50–60	.. ..	1,296	55	71,280
>60	Garth	224	66	14,784
60–80	North	592	68	40,256
”	South	464	66	30,624
>80	Aberdare	56	87	4,872
80–100	.. ..	96	92	8,832
>100	Snowdon.	72	104	7,488
	Total . .	7,376	—	365,320
	Isle of Man.			
25–30	.. ..	64	28	1,792
30–35	.. ..	56	32·5	1,820
35–40	.. ..	48	37·5	1,800
>40	.. ..	56	42	2,352
	Total . .	224	—	7,764
	Scotland.			
<25	Moray Firth	224	24	5,376
25–30	.. ..	2,368	28	66,304
30–35	.. ..	5,280	32·5	171,600
>35	Insch.	176	35·5	6,248
35–40	.. ..	4,400	37·5	165,000
40–50	.. ..	5,440	45	244,800
>50	Moffat	1,525	53·5	81,587
50–60	.. ..	3,040	55	167,200
60–80	.. ..	3,520	70	246,400
>80	Crianlarich	576	86	49,536
80–100	.. ..	672	89	59,808
>100	.. ..	192	106	20,352
	Total . .	27,413	—	1,284,211
	Ireland.			
<30	Dublin	704	29	20,416
30–35	.. ..	5,440	33	179,520
35–40	.. ..	7,660	37·5	287,250
>40	Ballymena	352	42	14,784
”	Newcastle	160	46	7,360
40–50	.. ..	13,024	43	560,032
50–60	.. ..	3,872	54	209,088
>60	Bantry	1,232	70	86,240
”	Clifden	250	70	17,500
	Total . .	32,694	—	1,382,190

TABLE III.—MEAN AND EXTREME RAINFALL AT 291 STATIONS IN THE BRITISH ISLES.

County.	Name of Station.	Height above Ground. Ft.	In.	Height above Sea. Feet.	Maximum Year. Inches.	Date.	Minimum Year. Inches.	Date.	Mean 1870–99. Inches.	—
Middlesex	Staines, Knowle Green	5	2	..	36·10	1872	18·40	1884	24·84	
"	London, Camden Square	0	8	111	34·08	1878	17·69	1898	25·16	
Surrey	Haslemere, Weycombe	4 1	0 0	583 562	49·09	1872	24·81	1892	33·19	Moved 50 yds. Dec. 1891.
"	Red Hill, Oxford Road	1	0	300	39·07	1877	22·59	1898	30·11	
Kent	Tenterden . . . o.g.	1	5	190	37·90	1877	20·87	1898	28·36	
"	Acrise, School House	1	0	504	47·51	1877	(26·00)	1870	36·79	
"	Tonbridge, Beech Hurst	1	6	96 102	36·24	1872	21·22	1898	27·72	Moved from St. Mary's in 1895.
"	Selling, Harefield	2	6	217	41·79	1872	22·78	1884	29·55	
"	Greenwich, Royal Observatory	0	5	155	31·36	1879	18·05	1884	23·83	
Sussex, West	Arundel, Patching	1	0	180	40·82	1872	23·55	1887	30·73	
" "	Chichester, Chilgrove	0	6	284	45·11	1877	25·31	1887	33·82	
" East	Eastbourne, Osborne House	1	0	12	41·55	1872	22·80	1898	30·98	
" "	Falmer	3	0	312	43·81	1877	24·41	1898	33·58	
" "	Maresfield, Forest Lodge	1	2	247	46·15	1872	22·16	1898	31·45	
Hampshire, I. of Wight	Osborne, Newbarn Cottage	0	8	172	39·38	1872	21·96	1870	28·12	Moved 64 yds. Feb. 28, 1895.
"	Basingstoke, Chapel Hill	1	0	328	36·57	1872	20·64	1870	27·93	
Berkshire	Newbury, Welford Park . . o.g.	1	0	335	39·30	1872	21·29	1870	30·29	Moved 86 feet 1 Jan. 1877.
Hertfordshire	St. Albans, Gorhambury	2	6	425	38·15	1872	19·06	1898	28·44	
"	Ware, Much Hadham	1	0	222	32·20	1872	18·68	1870	25·69	
Buckinghamshire	Aylesbury, New Road	1	0	280	39·25	1879	18·10	1893	26·90	
Oxfordshire	Henley-on-Thames, Greys	1	8	370	38·11	1872	19·89	1898	27·47	
"	Oxford, Magdalen College	1	0	186	32·40	1875	16·04	1870	24·54	
Northamptonshire	Towcester, Easton Neston	1	0	340	36·72	1872	15·40?	1870	26·80	'70 & '74 small.
"	Wellingborough, Croyland Abbey	0	3	..	36·16	1882	17·21	1870	25·31	
Huntingdonshire	Whittlesea Mere	1	6	..	33·70	1872	14·46	1887	23·09	
Bedfordshire	Stotfold [Baldock]	1	0	220	30·06	1872	15·88	1870	23·55	

TABLE III.—*continued.*

County.	Name of Station.	Height above Ground. Ft.	In.	Height above Sea.	Maximum Year.	Date.	Minimum Year.	Date.	Mean 1870–99.	
		Ft.	In.	Feet.	Inches.		Inches.		Inches.	
Cambridgeshire	Cambridge Observatory	1	0	85	31·50	1879	14·25	1870	23·07	
”	Upwell, Marmont Priory Lock	1	0	..	32·35	1872	15·27	1887	21·93	
Essex	Shoeburyness	7 2	0 6	18 3	33·24	1872	14·20	1874	19·75	Moved $1\frac{1}{10}$ m. E. Sept. 1895.
”	Chelmsford, High Street	1	0	86	30·80	1879	16·99	1887	22·96	
”	Earls Colne, Chalkney House	1	0	180	..	..	..	..	(23·60)	
Suffolk	Ipswich, Bishop's Hill	1	0	104	35·68	1872	14·97	1874	23·48	
”	Bury St. Edmunds, Westley	1	0	226	33·18	1872	16·82	1874	25·39	
Norfolk	Diss	1	0	96	..	...	..	..	25.20	
”	Geldeston [Beccles] . . 5-inch g.	1	0	38	33·91	1872	18·09	1893	23·93	
”	Swaffham, Dunham	1	1	320	44·46	1872	20·68	1898	28·41	
”	Cawston	1	0	135	37·31	1872	21·09	1874	27·28	
”	Hillington School	3	6	93	37·26	1872	20·17	1874	27·17	
”	Burnham Overy	5	3	..	33·67	1872	18·19	1874	25·26	
Wiltshire	Landford	1	10	167	43·74	1872	20·03	1887	30·16	
”	Salisbury Plain, Chitterne House	4	0	319	36·69	1891	21·48	1892	28·56	
”	Ludgershall	0	8	422	41·72	1872	23·17	1870	31·81	
Dorsetshire	Weymouth, Osmington Lodge	1	0	242	...	..	..	..	(33·20)	
”	Cerne Abbas, Melbury	2	9	500	60.23	1872	26·02	1887	38.62	
”	Wimborne Minster, Chalbury	2	0	338	46 85	1872	22·47	1887	31·06	
”	Shaftsbury	1	3	722	44·82	1882	23·77	1870	33·37	
Devonshire	Ashburton, Druid House	1	0	572	71·50	1872	36·61	1889	52·92	
”	Clevelands [Lyme Regis]	1	11	465	46·53	1872	22·24	1870	35·67	
”	Exeter, Manston Terrace	1	0	166	..	..	..	..	31·54	
”	Okehampton, Oaklands	1	0	521	68·37	1872	33·78	1870	47·50	
”	South Molton, Castle Hill	3 1	5 0	320 363	64·82	1872	31·84	1887	43·93	Moved 150 feet in 1883.
”	Barnstaple, Arlington Court	1	1	613	76·17	1882	(38·00)	1870	53·30	

TABLE III.—*continued.*

County.	Name of Station.	Height above Ground.	Height above Sea.	Maximum Year.	Date.	Minimum Year.	Date.	Mean. 1870–99.	—
		Ft. In.	Feet.	Inches.		Inches.		Inches.	
Cornwall	Falmouth, Carclew	0 9	..	62·60	1872	30·65	1887	45·55	
"	St. Ives, Phillack Rectory	1 0	70	48·50	1872	24·16	1887	36·68	
"	St. Agnes	1 3	278	53·87	1872	25·60	1887	33·19	
"	St. Austell, Trevarna	0 6	300	62·42	1872	33·26	1870	47·16	
"	Saltash, Pentillie Castle	1 3	150	72·84	1872	34·27	1887	50·71	
"	Launceston, Altarnon	1 0	570	84·11	1872	41·11	1887	59·93	
"	Bude	1 0	16	..	..	..	..	(34·10)	
Somersetshire	Ilminster, White Lackington	1 0	136	51·40	1872	23·14	1887	34·23	
"	Milverton, The Nook	1 0	265	..	..	..	..	35·90	
"	Glastonbury, Street	1 0	70	38·78	1876	21·23	1892	30·40	
"	Batheaston Reservoir	2 0	248	44·26	1882	17·85	1870	31·22	
Gloucestershire	Clifton, Pembroke Road	0 10	215	48·46	1882	23·20	1870	35·45	
"	Fairford, Kempsford	0 8	..	36·74	1882	17·63	1870	26·08	
"	Berkeley, Salter Street	{8 0 / 1 6}	60	38·32	1882	20·23	1893	28·33	{Moved 200 yards E. in 1893.
"	Cheltenham, Heath Lodge	1 0	206	38·21	1882	19·51	1892	27·82	
Herefordshire	Ross, The Graig	1 0	213	41·43	1872	20·13	1893	29·51	
"	Kington, Lynhales	1 0	566	47·00	1872	21·89	1870	33·56	
Shropshire	Church Stretton, Woolstaston	1 0	800	55·24	1872	23·49	1887	33·04	
"	Shifnal, Haughton Hall	3 6	355	44·06	1872	21·14	1898	28·21	
"	Oswestry, Hengoed	6 0	470	..	..	..	..	(34·33)	
"	Adderley Rectory	0 9	287	46·26	1872	20·82	1887	29·13	
Staffordshire	Penkridge, Rodbaston	1 0	324	48·16	1872	(20·00)	1870	29·10	
"	Burton, Rangemore	5 6	424	48·72	1872	19·18	1887	28·01	
"	Stoke, Stanley Reservoir	3 1	550	50·26	1872	19·89	1887	29·00	
Worcestershire	Northwick Park	1 6	410	40·59	1872	19·64	1892	29·22	
"	Great Malvern, Church Street	4 0	353	..	..	..	..	29·00	
"	Tenbury, Orleton	0 9	193	44·16	1872	(20·00)	1898	29·97	

TABLE III.—*continued.*

County.	Name of Station.	Height above Ground.	Height above Sea.	Maximum Year.	Date.	Minimum Year.	Date.	Mean 1870-99.	—
		Ft. In.	Ft. In.	Inches.		Inches.		Inches.	
Warwickshire	Warwick, Barford Rectory	0 8	167	37·26	1872	16·74	1887	25·29	
"	Coventry, Priory Row	1 2	279	39·48	1872	20·43	1893	27·96	
"	Birmingham, Botanic Gardens	5 2	505	42·16	1872	19·75	1893	27·16	
Leicestershire	Thornton Reservoir	1 2	371	36·43	1872	19·33	{1870, 1887}	26·48	
Rutlandshire	Burley-on-the-Hill	1 0	506	37·91	1872	17·40	1874	26·87	
Lincolnshire	Spalding, Pode Hole	0 3	20	37·12	1880	15·13	1887	24·16	
"	Stubton (Newark)	4 6	94	36·49	1872	17·56	1893	24·87	
"	Horncastle, Miningsby	0 6	135	34·73	1883	17·06	1890	24·77	
"	Lincoln, St. Botolph's	1 3	25	35·16	1872	16·76	1874	24·42	
"	Louth, Gospelgate	6 0	111	41·37	1872	20·89	1884	28·86	
"	Stockwith	3 6	21	34·37	1882	14·94	1874	23·22	
Nottinghamshire	Eastwood Colliery	1 0	245	41·31	1872	18·12	1887	29·00	
Derbyshire	Matlock Bath	1 6	500	56·21	1872	23·22	1887	35·07	
"	Killamarch, Norwood	3 6	238	35·93	1880	17·99	1887	26·30	
Cheshire	Middlewich, Bostock Hall	2 9	157	45·50	1872	19·82	1887	30·21	
"	Bollington, Spond's Hill	3 6	1,279	53·84	1872	18·97	1887	34·20	
"	Altrincham, Barrington House	3 0	105	54·91	1872	22·06	1887	33·98	
"	Bidston Observatory	1 0	189	45·66	1872	20·82	1887	28·99	
"	Woodhead Reservoir	0 10	660	64·31	1872	29·38	1887	48·85	
Lancashire	Wigan Waterworks	1 6	225	54·84	1872	22·12	1887	36·82	
"	Rochdale, Naden Dean	1 6	947	60·21	1872	25·54	1887	40·23	
"	Southport, Hesketh Park	2 8	23	48·48	1872	23·80	1887	33·22	
"	Clitheroe, Downham Hall	1 6	464	54·96	1877	30·38	1887	41·88	
"	Garstang, Grizedale Reservoir	1 3	519	63·24	1872	31·81	1887	44·61	
"	Escowbeck, Caton	3 0	150	62·75	1872	28·50	1887	41·01	
"	Ulverston, Poaka Beck	1 5	512	71·40	1877	35·17	1887	51·80	

TABLE III.—*continued.*

County.	Name of Station.	Height above Ground.	Height above Sea.	Maximum Year.	Date.	Minimum Year.	Date.	Mean 1870–99.	—
		Ft. In.	Feet.	Inches.		Inches.		Inches.	
Yorkshire, West Riding	Doncaster, Magdalens	4 9	46	38·39	1872	16·21	1887	24·82	
„ „	Barnsley, Church Street	5 2	350	45·54	1872	17·20	1887	27·28	
„ „	Longwood, Bilberry Edge	1 2	1090	54·71	1872	22·43	1887	37·35	
„ „	Halifax, Walshaw Dean	0 3	1380	64·40	1872	30·04	1887	46·27	{Moved 60 yds. in Dec. 1889.
„ „	South Milford Rectory	1 4	60	41·36	1872	17·05	1887	26·08	
„ „	Knaresborough, Farnham	1 0	170	39·07	1872	18·92	1887	26·70	
„ „	Pateley Bridge, Castle Stead	1 0	410	61·23	1872	30·24	1887	41·72	
„ „	Arncliffe Vicarage	2 9	734	79·49	1877	42·36	1887	60·96	
„ „	Sedbergh, Thorns Hall	1 6	400	77·02	1872	35·46	1887	52·50	
„ East Riding	Patrington, Spurn Head	1 0	27	..	..	..	..	19·90	
„ „	Hull, Pearson Park	0 6	6	36·73	1872	17·57	1887	27·02	
„ „	Pocklington, Warter	1 10	230	46·75	1872	19·10	1887	30·75	
„ North Riding	Old Malton	1 0	75	41·79	1872	19·60	1887	26·71	
„ „	Bedale, Thorpe Perrow	1 6	170	44·22	1872	19·20	1887	27·09	
„ „	Northallerton, Osmotherly	3 0	650	46·41	1872	19·22	1898	27·35	
„ „	Forcett Park [Darlington]	1 0	851	..	..	..	..	29·70	
„ „	Whitby, Guisborough Road	2 0	184	..	..	..	..	26·10	
Durham	Hartlepool, Hurworth Burn	0 7	360	43·61	1872	18·96	1884	27·66	
„	Wolsingham	1 0	464	53·80	1872	24·98	1873	34·75	
Northumberland	Haltwhistle, Unthank Hall	0 9	380	47·80	1877	26·14	1885	35·46	
„	Newcastle, Town Moor	2 0	201	41·49	1872	20·35	1873	27·99	
„	Gunnerton Burn, Camphill	0 6	676	44·57	1872	22·11	1885	29·91	
„	Morpeth, Meldon Park	1 0	350	..	..	..	..	31·14	
„	Redeswater Catcleugh	1 0	794	..	..	..	..	(38·80)	
„	Howick Hall	0 10	121	41·32	1872	20·58	1898	28·29	
„	Ilderton, Lilburn Tower	6 0	300	46·59	1872	18·91	1893	29·19	
Cumberland	**Seathwaite** 5 inch g.	1 0	422	182·05	1872	101·57	1887	133·53	
„	**Cleator, The Flosh**	1 11	208	65·17	1877	33·04	1887	47·45	

TABLE III.—*continued.*

County.	Name of Station.	Height above Ground.		Height above Sea.	Maximum Amount.	Date.	Minimum Amount.	Date.	Mean 1870–99.	
		Ft.	In.	Feet.	Inches.		Inches.		Inches.	
Cumberland (*cont.*)	Bassenthwaite, Mirehouse	0	7	310	70·62	1872	36·27	1887	49·60	
„	Maryport, Netherhall	0	6	27	47·65	1877	26·56	1880	35·73	
„	Carlisle, Scaleby	1	1	112	45·78	1877	26·89	1870	33·52	
Westmorland	Kirkby Stephen	1	0	574	59·90	1894	28·20	1887	42·12	
„	Lowther Castle [Penrith]	3	0	750	..	..	..	..	(38·89)	
Monmouthshire	Llanfrechfa Grange	4	0	326	62·92	1877	30·02	1890	44·94	
„	Abergavenny, Larchfield	1	0	240	52·20	1872	26·52	1887	37·82	
Glamorganshire	Cardiff, Ely	1	0	53	56·73	1882	31·59	1887	42·81	
„	Neath, Glyncorrwg	4	6	717	117·57	1872	59·86	1889	86·14	
Carmarthenshire	Llanelly, Cwmleiddi W. W.	3	0	240	..	..	..	..	(46·90)	
„	Carmarthen, Joint Co. Asylum	1	0	189	..	..	..	..	(49·60)	
„	Llandovery	1	0	217	..	..	..	..	(50·00)	
Pembrokeshire	Haverfordwest, High Street	1	0	95	69·78	1872	35·23	1887	47·88	
„	Castle Malgwyn [Llechryd]	1	2	..	68·26	1872	29·23	1887	43·85	
Cardiganshire	Aberystwith, Gogerddan	1	0	80	62·26	1882	34·49	1887	(45·41)	
Brecknockshire	Llandefaelog-fach Rectory	1	0	660	..	..	..	..	(44·60)	
Radnorshire	Rhayader, Nantgwillt o. g.	1	0	767	93·86	1872	43·43	1892	61·45	
Montgomery	Llangwrig, Ystradolwyn-fawr	1	0	950	83·80	1872	33·70	1887	53·31	
„	Churchstoke, Mellington Hall	1	6	540	..	..	..	..	(31·80)	
Flintshire	St. Asaph, Nantlys	1	0	173	47·82	1872	21·50	1893	28·71	
„	Rossett, Trevalyn Hall	1	0	58	47·90	1872	21·88	1893	27·58	
Merionethshire	**Dolgelly, Brithdir**	1	6	465	100·39	1872	44·99	1887	66·67	
„	**Bala, Henblas.**	1	0	590	75·18	1872	38·97	1887	51·45	Eyrl Aran from 1887.
Carnarvon	**Llanystwmdwy, Talarvor**	2	0	49	55·31	1877	23·55	1873	35·83	
„	Llanfairfechan	0	8	150	..	..	..	..	39·47	
Anglesey	Llanerchymedd **Llwydiarth Esgob**	1	0	112	(58·74)	1872	27·98	1887	38·21	

TABLE III.—*continued.*

County.	Name of Stations.	Height above Ground.	Height above Sea.	Maximum Amount.	Date.	Minimum Amount.	Date.	1870–99.
		Ft. In.	Feet.	Inches.		Inches.		Inches.
Wigtonshire	Corsewall	3 4	22?	49·85	1877	23·61	1869	32·85
Kircudbright . . .	Auchencairn, Torr House . . .	0 8	30	70·55	1877	34·10	1880	46·45
" . . .	Gatehouse, Cally	1 0	120	70·57	1877	36·12	1878	48·74
" . . .	New Galloway, Glenlee	1 3	234	..	..	..	..	(56·40)
" . . .	Irongray, Drumpark	1 0	230	80·20	1877	40·10	1880	54·35
Dumfriesshire . . .	Canonbie, Byreburnfoot	0 9	160	64·25	1877	28·75?	1887	43·84
" . . .	Durrisdeer, Drumlanrig Castle . .	0 6	191	71·60	1872	26·50	1895	44·28
" . . .	Moffat, Ericstane	0 6	550	86·00	1872	37·18	1887	54·97
Roxburgh	Hawick, Wolfelee	0 6	587	57·04	1872	29·91	1887	40·07
Selkirk	Galashiels, Abbotsford Road . .	0 8	416	49·02	1872	25·39	1870	33·82
Berwick	Marchmont House	1 0	500	55·20	1872	26·43	1893	34·94
"	West Foulden	1 0	250	(43·30)	1872	19·24	1898	27·20
Haddington	Prestonkirk, Smeaton	..	100	..	..	..	..	25·72
Edinburgh	Pentland Hills, Clubbiedean Res. .	0 6	750	53·20	1872	27·60	1870	35·79
Lanarkshire	Douglas, Newmains	0 4	783	..	..	..	..	(45·60)
"	Biggar, Cambus Wallace	0 6	748	42·06	1872	21·00	1870	30·71
"	Airdrie, Hillend Reservoir . . .	4 6	620	(51·00)	1872	24·13	1870	37·30
Ayrshire	Girvan, Pinmore	1 0	187	67·66	1877	39·42	1895	48·87
"	Old Cumnock	1 3	380	..	..	..	..	(41·10)
"	Kilmarnock, North Craig . . .	1 0	319	51·46	1872	27·47	1887	39·46
"	Ardrossan, Kirkhall	2 9	106	..	..	..	..	(36·80)
Renfrewshire . . .	Paisley W. W., Stanely	1 0	190	65·82	1877	30·24	1887	42.45
"	Shaws W. W., Loch Thom . . .	1 0	643	90·03	1877	48·49	1895	64·08
Dumbartonshire . . .	Arrochar	0 9	12	112·53	1872	49.14	1895	76·64
Stirlingshire	Strathblane, Mugdock Reservoir .	9 6	320	63·60	1872	36·60	1887	47·70
"	Glengyle	..	380	128·50	1877	67·00	1887	92·41
Bute "	Arran, Pladda	3 3	55?	53·81	1877	27·63	1870	39·44

TABLE III.—*continued.*

County.	Name of Station.	Height above Ground.	Height above Sea.	Maximum Amount.	Date.	Minimum Amount.	Date.	1870–99.	—
		Ft. In.	Feet.	Inches.		Inches.		Inches.	
Argyll, Mainland	Lochgilphead, Kilmory	0 4	108	..	..	..	..	(59·99)	
,, ,,	Appin, Airds	0 11	41	76·50	1877	41·64	1895	55·90	
,, ,,	Loch Sunart, Glenborrodale	0 2	60	88·66	1890	42·85	1875	65·06	
,, ,,	Loch Eil, Corran	0 4	14?	109·55	1877	57·87	1875	77·08	
,, Insular	Mull of Cantire	..	279?	66·90	1872	25·77	1889	40·83	
,, ,,	Skipness Castle	1 6	27	65·50	1877	36·50	1887	49·18	
,, ,,	Islay, Lochindaul	..	..	58·32	1877	33·75	1893	44·84	
Kinross-shire	Loch Leven, Sluice	0 7	360	49·80	1876	23·20	1870	36·20	
Fifeshire	Kilmany, Montquhanie House	1 3	240	46·50	1872	20·10	1887	28·53	
Perthshire	Culross, Westgrange	0 2	116	53·80	1872	23·53	1898	35·30	
,,	Dunblane, Kippenross	0 4	150	51·25	1899	22·20	1887	36·60	
,,	Callander, The Gart	0 6	242	78·88	1872	35·60	1879	54·19	
,,	Crieff, Ochtertyre	3 0	326	63·90	1872	28·85	1889	(41·50)	
,,	Pitlochrie, Fasganevin	1 0	350	..	..	..	..	(36·00)	
,,	Dalnaspidal	3 0	1,414	..	..	..	..	(61·02)	
Forfarshire	Dundee, Eastern Necropolis	0 5	199	44·55	1876	20·15	1887	28·95	
,,	Kirriemuir, Lintrathen	1 0	700	..	..	..	..	(35·60)	
,,	Montrose, Sunnyside Asylum	0 10	200	46·44	1872	19·07	1887	29·16	
Kincardine	Fettercairn	0 8	237	57·70	1872	22·88	1887	34·08	
Aberdeenshire	Braemar	0 9	1,114	59·25	1872	25·10	1887	36·07	
,,	Cromar, Logie Coldstone Manse	1 0	694	48·38	1872	22·38	1887	30·14	
,,	Aberdeen, Rose Street	0 5	95	39·81	1872	24·00	1870	29·15	
,,	Inverurie Manse	0 4	220	..	..	..	..	(35·80)	
,,	Old Deer	2 0	135	47·51	1872	(27·00)	1870	32·50	
Banffshire	Keith	1 0	364	45·81	1872	25·50	1870	32·72	
Elgin	Grantown	1 1	712	42·63	1872	24·67	1881	31·00	
,,	Forres	1 0	25	33·11	1872	17·68	1897	24·33	

TABLE III.—*continued.*

County.	Name of Station.	Height above Ground.	Height above Sea.	Maximum Amount.	Date.	Minimum Amount.	Date.	Mean 1870–99.	—
		Ft. In.	Feet.	Inches.		Inches.		Inches.	
Nairn	Cawdor, Budgate	1 0	250	38·64	1877	21·16	1870	29·37	
Ross, West	Applecross Gardens	1 0	70	70·82	1872	42·99	1887	54·80	
,, ,,	Strathconan, Dalbreac	1 0	450	..	..	..	..	(50·90)	
,, ,,	Braemore House	0 7	750	79·96	1885	34·37	1870	58·56	
,, ,,	Lewis, Stornoway. Met.Off.g.	1 0	24	76·80	1872	33·68	1880	50·73	
,, East	Alness, Ardross Castle	1 0	450	46·87	1882	26·97	1887	37·84	
,, ,,	Fearn, Lower Pitkerrie	1 0	{58, 95}	32·19	1877	16·61	1897	23·52	{Moved to Lower Pitkerrie in '82.
Inverness, West	Loch Shiel, Glenaladale	1 0	50?	133·02	1898	83·60	1895	105·29	
,, ,,	Glenquoich	2 4	660	157·71	1874	(85·00)	1870	108·26	
,, ,,	Isle of Skye, Oronsay	0 6	15?	101·15	1874	30 62	1881	52·03	
,, ,,	,, ,, Kyleakin	0 2	3?	107·10	1874	38·30	1899	64·52	
,, ,,	,, ,, Sligachen	1 6	40	..	..	..	..	(91·00)	
,, ,,	,, ,, Dunvegan	1 0	24	..	..	..	..	(70·30)	
,, ,,	Rona	..	..	69·80	1882	26·43	1886	45·01	
,, ,,	South Uist, Ushenish	0 4	157?	109·30?	1884	35·35	1875	59·89	
,, ,,	North Uist, Monach	..	..	72·40	1884	38·40	1880	48·37	
,, East	Glenstrathfarrer	1 0	461	..	..	..	..	(57·90)	
Sutherland	Golspie, Dunrobin Castle, M.	0 3	13	41·65	1877	22·90	1897	31·03	
,,	Lairg	{3 4, 0 10}	{451, 385?}	51·13	1877	26·06	1897	36·47	{Diff. gauge from Oct. '96.
,,	Scourie	0 5	28	..	..	..	..	42·47	
,,	Cape Wrath	3 6	255	64·72	1885	27·66	1845	40·48	
Caithness	Watten	2 6	75	..	..	..	..	(27·40)	
,,	Thurso, Holburnhead	0 8	60?	53·30	1898	21·97	1870	31·20	
Orkney	S. Ronaldshay, Roeberry	1 2	101	54·26	1898	22·10	1870	33·15	
,,	Hoy, Graemsay, East-High Light	3 4	27?	45·45	1898	24·05	1897	33·97	

TABLE III.—*continued.*

County.	Name of Station.	Height above Ground.	Height above Sea.	Maximum Amount.	Date.	Minimum Amount.	Date.	Mean 1870–99.	
		Ft. In.	Feet.	Inches.		Inches.		Inches.	
Cork	Dunmanway, Coolkelure	1 6	500	..	..	..	..	71·10	
,,	Cork, Queen's College	6 0 1 0	65 60	61·57	1872	26·45	1887	41·28	g. lowered 5 ft. in 1876.
,,	Fermoy, Gas Works	1 1	..	..	..	..	..	(38·20)	
Kerry	Darrynane Abbey	1 1	13	..	..	..	..	(51·70)	
,,	Kenmare, Derreen	1 0	74	..	..	..	..	(69·50)	
,,	Valencia, Telegraph Station	1 0	12	..	..	..	..	(55·90)	
,,	Killarney, Woodlawn	1 0	96	..	..	..	..	(58·10)	
Waterford	Portlaw, Mayfield	20 0 4 0	50 70	55·60	1872	26·66	1887	42·38	20 ft. above ground from 1870–79.
,,	Glenam [Clonmel]	1 4	80	59·13	1872	27·34	1887	42·17	
Tipperary	Tipperary, Henry Street	1 0	400?	..	..	..	..	38·60	
,,	Nenagh, Castle Lough	1 3	120	..	..	..	..	(40·00)	
Limerick	Foynes	1 0	104	..	..	..	..	40·69	
Clare	Ennis	3 2	21	..	..	..	..	(40·00)	
,,	Miltown Malbay	1 0	400	..	..	..	..	(44·50)	
Wexford	New Ross, Longraigue	1 1	210	61·59	1872	24·95	1887	40·54	
,,	Enniscorthy, Ballyhyland	1 0	365	57·25	1872	27·33	1887	42·87	
,,	Gorey, Courtown House	3 0	80	52·10	1872	22·91	1887	35·72	
Kilkenny	Inistioge, Woodstock	4 6 1 0	400	64·05	1872	21·89	1893	42·27	
Wicklow	Bray, Fassaroe	5 0	250	51·39	1883	26·25	1893	40·55	
Carlow	Carlow, Browne's Hill	1 0	291	47·29	1872	22·49	1887	34·44	
Queen's County	Abbey Leix, Blandsford	3 0	532	(45·00)	1872	24·59	1887	35·20	
King's County	Parsonstown, Birr Castle	0 11	183	40·08	1877	23·47	1887	33·06	
Kildare	Straffan House	2 0	240	..	..	..	..	(32·20)	
Dublin	Dublin, FitzWilliam Square	3 6 1 2	54	35·57	1872	16·60	1887	27·75	New gauge in 1887.
,,	Balbriggan, Laragh	1 0	57	43·26	1872	20·43	1887	30·16	

TABLE III.—*continued.*

County.	Name of Station.	Height above Ground.	Height above Sea.	Maximum Amount.	Date.	Minimum Amount.	Date.	Mean 1870–99.	—
		Ft. In.	Feet.	Inches.		Inches.		Inches.	
Meath	Moynalty, Westland	1 4	265	..	..	..	..	(37·40)	
Westmeath	Mullingar, Belvedere	1 0	367	..	..	..	..	(36·50)	
,,	Athlone, Twyford	5 0	188	51·10	1877	28·00	1887	38·42	
Louth	Dundalk, Farndreg	1 0	90	..	..	..	..	(30·90)	
Longford	Edgeworthstown, Currygrane Ho.	1 1	265	..	..	..	..	(36·20)	
Galway	**Galway, Queen's College**	1 0 9 0	22 30	56·37	1872	31·49	1888	41·59	Gauge 1 ft. above g. 1884–1894.
,,	Ballinasloe	0 6	150	46·46	1877	26·61	1887	37·04	Moved 67 yds. in 1893.
,,	Clifden, Kylemore House	1 0	105	..	..	..	..	(80·20)	
,,	Tuam, Gardenfield	6 0	160	48·94	1886	33·34	1879	41·01	
Mayo	Ballinrobe, Kilrush	1 0	120	..	..	..	..	(41·80)	
,,	Westport, Oldhead House	1 7	100	..	..	..	..	52·80	
,,	Crossmolina, Enniscoe	0 11	74	..	..	..	..	(50·50)	
Sligo	Collooney, Markree Observatory	0 6	129	(55·50)	1872	34·10	1883	41·83	
Leitrim	Ballinamore, Lawderdale	1 0	275	..	..	..	..	(41·50)	
Cavan	Belturbet, Red Hills	0 9	208	45·99	1897	24·50	1887	35·19	
Armagh	Armagh, Observatory	1 0	205	39·66	1872	22·29	1870	31·36	
Down	**Seaforde**	0 5	180	57·57	1872	24·66	1887	38·61	
,,	**Waringstown**	0 8	191	44·74	1872	24·22	1887	33·73	
,,	Donaghadee	1 6	30	..	..	..	..	(32·00)	
Antrim	Belfast, Queen's College	7 4	68	44·46	1872	23·45	1887	33·23	
,,	Ballymena, Harryville	1 0	150	..	..	..	..	(39·60)	
Londonderry	Garvagh, Moneydig	1 0	121	55·00	1872	30·28	1887	39·16	
Tyrone	Stewartstown, The Square	1 0	300	..	..	..	..	(35·10)	
,,	Omagh, Edenfel	1 0	280	46·31	1897	30·82	1885	37·85	
Donegal	Killybegs	1 0	30	..	..	..	..	(59·40)	
,,	Raphoe, Convoy House	1 0	110	56·25	1884	36·98	1897	44·67	
,,	Ardnadrean, Bloody Foreland	0 9	39	..	..	..	..	(45·60)	
,,	Moville, Prospect Villa	1 4	79	(57·51)	1872	31·55	1887	42·55	

TABLE IV.—AREA IN SQUARE MILES OF EACH ZONE OF AVERAGE RAINFALL OF THE BRITISH ISLES FOR THE PERIOD 1870–1899.

—	< 25	25–30	30–35	35–40	40–50	50–60	60–80	80–100	>100	Total.
England .	9,776	18,552	10,885	4,448	4,240	1,384	576	128	64	50,053
Wales .	..	128	528	1,328	2,592	1,296	1,280	152	72	7,376
I. of Man	..	64	56	48	56	..	..	..	..	224
Scotland .	224	2,368	5,280	4,576	5,440	4,565	3,520	1,248	192	27,413
Ireland .	..	704	5,440	7,660	13,536	3,872	1,482	..	..	32,694
British Isles. .	10,000	21,816	22,189	18,060	25,864	11,117	6,858	1,528	328	117,760

TABLE V.—AREA IN SQUARE MILES OF EACH ZONE OF RAINFALL OF THE BRITISH ISLES FOR THE YEAR 1872.

—	25–30	30–35	35–40	40–50	50–60	60–80	80–100	>100	Total.
England . .	1,884	8,944	10,178	16,532	7,936	3,606	730	232	50,042
Wales	..	..	..	332	756	3,900	1,828	361	7,277
Isle of Man . .	..	..	..	32	112	80	..	..	224
Scotland . .	..	..	1,266	7,720	6,766	7,240	2,904	1,856	27,752
Ireland	..	..	2,928	9,904	13,856	5,472	384	..	32,544
British Isles .	1,884	8,944	14,372	34,620	29,426	20,298	5,846	2,449	117,839

TABLE VI.—AREA IN SQUARE MILES OF EACH ZONE OF RAINFALL FOR THE BRITISH ISLES FOR THE YEAR 1887.

—	< 15	15–20	20–25	25–30	30–35	35–40	40–50	50–60	60–80	80–100	Total.
England	1,888	14,240	19,936	8,552	3,222	1,104	904	192	80	64	50,182
Wales .	..	..	608	1,408	1,600	1,548	1,872	232	104	..	7,372
Isle of Man.	..	..	48	136	40	..	..	..	..	..	224
Scotland	..	548	3,344	7,040	4,016	3,100	2,994	2,692	3,024	596	27,354
Ireland	..	636	7,536	9,248	4,372	4,464	5,088	768	48	..	32,680
British Isles.	1,888	15,444	31,472	26,384	13,750	10,216	10,858	3,884	3,256	660	117,812

Discussion.

The President. The PRESIDENT, in moving a vote of thanks to the Author for his valuable Paper, remarked that it was very satisfactory to find that the work so long and so well done by the late Mr. Symons was being continued and developed by the Author and those working with him. He had no personal knowledge of the subject of rainfall-observations, but he was assured by friends who dealt with questions of water-supply that accurate observations of rainfall, and the analyses of them made by observers like the Author, were of the highest value to engineers in their professional work.

The Author. The AUTHOR exhibited various lantern-slides, with a view to bring out clearly one or two of the points dealt with in the Paper. The first was a graphical representation of the facts given in the Tables on p. 295. The interesting feature, on which was based the selection of 30 years as a safe period in his researches, was that in the long continental series, while the average deviation of periods of 10 years and 20 years from the long-period mean was comparatively large, the average deviation of a period of 30 years was scarcely larger than the average deviation of a period of 40 years. In England that similarity was not quite so marked, the variation being a little greater; but in order to get any substantially better mean an average would be required of at least 50 years, and for that so few stations would be available that it would be impossible to construct maps without computing by far the greater number of the observations, thereby depriving the work of a large part of its value. In order to get accurate and trustworthy observations it was necessary to have good instruments and conscientious observers. A great deal of controversy had raged as to the best form of rain-gauge, and much of it had been settled by experiment about 30 years ago. Trials with gauges of various diameters, ranging from 1 inch to 2 feet, had shown that, if they were set perfectly level and observed with great care, exactly the same rainfall was registered by all of them; so that the size of the opening of the gauge was merely a matter of convenience. Most gauges were now made with an orifice of 5 inches, which was found to be ample. They were placed 1 foot above the ground, which was taken as standard height. The higher the gauge was raised above the ground, the smaller was the quantity of rain caught, owing, as had been clearly demonstrated, to the eddies caused by the wind about a prominent upstanding object. For that reason it was more important to have gauges placed

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at a uniform height than to have them of a uniform diameter. The Snowdon gauge had generally been adopted as the standard form for daily reading. It was designed to give effect to all the necessary precautions, and to measure falling snow fairly accurately. Snow was the great bugbear of rainfall observations; and most of the results rejected from the pages of "British Rainfall" were due to the difficulty of measuring snow in exposed situations, where there was much drifting. The next important point, after ensuring good instruments and conscientious observers, was to have those instruments and observers as widely and uniformly distributed as possible. With the other elements of climate the same necessity was not felt so much. A comparatively small number of well-distributed stations would give the average temperature or the average pressure of the atmosphere; but it required a number of stations to give the average rainfall, because rainfall was subject to many disturbing influences. The observing-power of the British Isles, which, when "British Rainfall" started in 1860, was represented by 168 observers, had grown by 1902 to 3,636 observers who sent in complete records. They were not all absolutely accurate, but they were nearly all conscientiously taken, and the result formed a magnificent basis for carrying on the work. By going back 30 years it was possible to obtain averages of a large number of stations; but for every 10 years farther back the number of stations throughout the country diminished very rapidly. Accordingly, it had been with feelings of great satisfaction that he had found the 30 years 1870–1899 to be, of all the periods of 30 years that could possibly have been taken since the beginning of observations in this country, the nearest to the long-period mean. Accordingly the result came very near what a real average of 50 years or even 70 years would show —certainly within 2 per cent. It was in Ireland and Scotland that additional observers were most required, in order to secure perfect rainfall-maps. He had said nothing about the variation of rainfall from year to year, because the subject was too large, and the labour of calculating the mean rainfall for the country, or extensive parts of the country, was too great to admit of its being undertaken systematically at present. The extremely wet year 1872 shot up as a solitary pinnacle from among comparatively dry years, and had been followed by a very wet spell, which had again been followed by an extremely dry spell, during which only a few years had reached or passed the average; and the driest year of all, 1887, had occurred in the midst of years that were not really much lower than their neighbours below the average. The year 1903,

The Author. unfortunately, for the purposes of the Paper, was not yet completed; but there was reason to believe that when completed it would give an average rainfall approximate to that of 1872, and perhaps surpassing it. That was not prophecy, because already in the greater part of the country the rainfall for the 10½ months of the year had exceeded the rainfall for the whole of any previous year for which records had been kept. When studying the distribution of rainfall over a considerable area of the earth's surface the observer was confronted by a series of new difficulties, some of which were referred to in the Paper. The British Isles occupied a position in the region of maximum rainfall of the North Temperate Zone, which made a study of their rainfall peculiarly difficult. That was perhaps an advantage, just as it had been an advantage to the science of geology that the geological structure of the British Isles was the most difficult of any part of the world. But the study of rainfall had not yet advanced so far as geology, though he hoped it was progressing. The point which he had kept before him in constructing the maps was to take notice of nothing except the actual figures of rainfall determined by observation, and the result was a series of maps which showed lines of equal actual rainfall, and not hypothetical lines. One subject of investigation was the comparison of the lines of equal rainfall with the lines of a contour-map of the British Isles, which showed how closely the areas of maximum rainfall coincided with the areas of high land. That was well known; but the question still requiring investigation was the quantitative relation between the two—between the height, slope and exposure of a given district, and the rainfall upon it. In describing the map of average rainfall over the British Isles (Fig. 1, Plate 2) he drew attention to the beautiful instance, in the south-east of England, of the Wealden district, where the configuration of the North Downs, the South Downs, and the Forest Ridge, was clearly outlined by the increase of rainfall corresponding with the height. The same thing was found in several of the other hill ranges; but in those of Shropshire it was not so well illustrated, because there were so few observers there that an extremely interesting district had been of necessity somewhat slurred over. In the district immediately to the east of Cross Fell, on the flanks of the Cheviots, there was an almost total want of rain-records; and although the rainfall was probably considerably higher there, it had been impossible to represent it, for want of data. It was quite certain that the estuary which led up to Carlisle, between the Lake District and the Southern Uplands of Scotland, was a region of comparatively

low rainfall, well under 35 inches per annum. Then there was the remarkable region of low rainfall bordering North Wales and the estuary of the Mersey; and in some parts where the Pennine rainfall extended into the great plain there was no apparent difference in the configuration of the country to account for one place being wetter than another. Those were some of the questions which required investigation before the problem could be fully worked out. In investigating the extreme years, the first point to be settled was whether those years were really typical of the wettest and driest years that could be expected. The moral to be drawn from Figs. 5 and 6, Plate 3, was that there was more likely to be a uniformly very wet year than a uniformly dry year; in other words, that an abundance of rain was more likely to occur over a considerable area than was a generally dry year over an area of equal extent. An interesting point in this connection was the extraordinary dryness of the east of England in a dry year, and its still more extraordinary relative dryness in a wet year. In fact, when the maps of maximum, minimum, and average rainfall were compared it would be found that the lines ran almost in the same positions. This showed that the same influences of configuration and prevailing wind were at work in the wettest and driest years as well as in the average year; and it also showed how prominent the geographical influences really were, and how important it was to be able to understand fully the relationship between rainfall and configuration. With regard to the ratio which the wettest and driest and average years bore to each other in different parts of the United Kingdom, the average for the whole of England and Wales in the wettest year was very nearly 50 per cent. higher than the mean, but the average in the driest year was scarcely more than 25 per cent. lower than the mean; while in Scotland and Ireland, with more insular climates, the range was still more restricted. This again showed that an extreme year was likely, over a wide area, to exceed more in wetness than in dryness. The Author.

Sir ALEXANDER R. BINNIE, Vice-President, did not know a subject which could more properly be brought before the Institution than the subject of rainfall; and when it was considered that rivers and lakes were all derived from rainfall, it would be seen that the subject was one which certainly merited considerable attention. The first thing that struck an ordinary observer of rainfall was that, among all the phenomena of Nature, it was perhaps one of the most variable. But on inquiring into that variability, the observer was at once brought face to face with the Sir Alexander Binnie.

Sir Alexander Binnie. question: "Variability from what?" Careful investigations in all parts of the world had led to the rough conclusion that if a rainfall-record was kept for a certain number of years, something would ultimately be arrived at which was called an average or a mean rainfall. The first point to which the Author had directed his attention was the number of years of observation necessary in order to obtain an average result, which would not be altered, although the records were continued for a greater number of years. The Author had arrived at the conclusion that 30 years' observation would afford that information. His own determination of 30 or 35 years, communicated to the Institution in 1892, and the Author's determination of 30 years, were clearly dependent upon the periods into which the total record was divided. The Author divided it into 10-year periods; he himself had divided it into 5-year periods, and he still believed that the true mean was somewhere between 30 and 35 years. He could give no reason, nor did the Author profess to give any, for that particular period, which lay somewhere in the neighbourhood of 33 years. Some hard-working and conscientious continental observers were not only coming gradually to the conclusion that 33 or 34 years was the proper period, but were trying to give a reason for their belief. The fact was fairly definite; ther eason for it was at present somewhat obscure. A mean rainfall having been derived, the next step was to determine within what probabilities that figure could be depended upon. The monumental work placed before the Institution that evening, arising out of the lifelong labours of the late Mr. Symons, F.R.S., was a concise answer to that question. The Author said it might be anticipated that for the British Isles the wettest year would exceed the average by 43 per cent., and the driest fall below it by 29 per cent. In his own Paper of 1892 he had given the figures as 45 per cent. and 24 per cent., respectively. If the matter was to be of any use to engineers as professional men, they must know a little more about the subject, and study it a little more deeply. To take his own case, in 1868 and 1869 he had been called upon to design and lay out waterworks of considerable magnitude in India, and had been faced by the fact that there were only three long records to go upon, very widely separated, namely, Calcutta, Madras, and Bombay; with a somewhat shorter record in the neighbourhood of Nagpur, where he was working.[1] He had begun

[1] "Nagpur Waterworks; with Observations on the Rainfall, the Flow from the Ground, and Evaporation at Nagpur; and on the Fluctuation of Rainfall in India and in other places." Minutes of Proceedings Inst. C.E., vol. xxxix. p. 54.

to compare those records, because he had had actually no records in the districts where the works were to be constructed. He had first attempted to find out within what limits he could depend upon the record in the exceptional circumstances of a tropical climate, where the rainfall was due mainly to the north-east and south-west monsoons; and he had at once been struck with the fact that the deviations from the mean were similar in kind, and almost identical in amount, with those with which he had been accustomed to deal under his old master, the late Mr. Bateman, F.R.S., Past-President of the Institution, in London. Out of that had arisen the idea that in order to study rainfall in its variations it was necessary to ignore—at all events to a large extent—the amount of the rainfall. The actual amount in any particular station, as the Author had lucidly shown, was a purely local circumstance. For instance, the average rainfall of Baku, on the Caspian, was about 10 inches; of Moulmein, 189 inches: how were these to be compared? Except that they had these mean rainfalls, one small and one large, there were no means of comparing them. When considering rainfall-records, he had been taught by Mr. Symons to reduce them to a percentage of the mean fall; and if that was done, instead of a confused mass of figures of inches of rainfall, varying with every climate and every position in which a rain-gauge could be set up, a lucid statement of the case was obtained. In his Papers of 1874 [1] and 1892 [2] he had shown what they meant. Considering, for instance, the fall of the maximum year, irrespective of the amount of rain that fell, England, Ireland, and Scotland he made out to be 45 per cent. above the average. For other countries he found the percentage above the average to be:—Norway, Denmark, Holland and Belgium 48 per cent.; France 61 per cent., Italy 59 per cent., Switzerland 47 per cent., Germany 39 per cent., Bavaria and Austria 44 per cent., Russia 66 per cent., India 62 per cent., Africa 66 per cent., Australia 56 per cent., and North America and Canada 41 per cent. The average excess of the maximum year shown by what might be called typical observations throughout the world was 51 per cent. above the mean, as compared with 45 per cent. in the British Isles. When the records—whether for the United Kingdom or for more distant countries—had been analyzed, there was, as the Author pointed out, still a difference of 2 per cent. At present that 2 per cent. might be put down to errors

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[1] Minutes of Proceedings Inst. C.E., vol. xxxix. p. 54.
[2] *Ibid*, vol. cix. p. 89.

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of judgment or to errors of calculation; but he was content to let it rest as a difference, because in studying so abstruse a subject it was necessary to guard against anything like prepossession. It must not be assumed that it was an error at all, because it haunted investigators in many investigations. As he had shown in his Paper of 1892, it traversed every kind of calculation made about rainfall, and therefore he was not prepared to say that it was an error due either to observation or to judgment: it was a thing to be held in suspense until more was known about the whole subject. The difference between the average of 45 per cent. in the British Isles, and of 51 per cent. throughout the world, was small; and the minimum years were in still better accord. In the British Isles 24 per cent. below the average, 39 per cent. in Scandinavia and Holland, 41 per cent. in France, 45 per cent. in Italy, 45 per cent. in Switzerland, 39 per cent. in Germany, 44 per cent. in Bavaria and Austria, 47 per cent. in Russia, 48 per cent. in India, 47 per cent. in Australia, and 32 per cent. in North America. When figures all over the world were found coinciding in that remarkable manner, the mind was led inevitably to the conclusion that, apart from quantity—and these figures were quite irrespective of the actual quantity of rain that fell—there was some force at work in Nature of which nothing was known, but which kept the deviation of rainfall from the mean within certain clearly marked limits. Again, taking the stations which he had dealt with in his 1892 Paper, in different countries, and grouping them according to the amount of their mean annual rainfall, it was found that the average excess of the falls in the maximum years over the mean falls was: for the group of stations having mean rainfalls of 50 inches and upwards, 53 per cent.; 40–49 inches, 46 per cent.; 30–39 inches, 50 per cent.; 25–29 inches, 47 per cent.; 20–24 inches, 49 per cent.; the average being 49 per cent., against his own 45 per cent. and the Author's 43 per cent. for the British Isles. With such imperfect materials there could be no better approximation to a standard. Analyzing the average defect of the falls in minimum years in the same manner, the results were: for the group of stations having mean rainfalls of 50 inches and upwards, 39 per cent.; 40–49 inches, 38 per cent.; 30–39 inches, 40 per cent.; 25–29 inches, 40 per cent.; 20–24 inches, 39 per cent.; the average being 40 per cent. The study of so great a question, affecting engineers working in all parts of the known world, was of the utmost importance; and he believed that if they would devote attention to the matter, scientific advance would be materially assisted by regarding rain-

fall not as a local circumstance, not as a matter of a few inches more or less, but as a great natural phenomenon; and by endeavouring to arrive at some measure of the limits of deviation of the forces at work. With that clearly in view, it would be possible to begin to speculate on causes with advantage, but it was necessary at present—and, as far as he could see, it would be for some time to come—to devote study to a careful and systematic determination of the facts of the actual distribution of rainfall throughout the world. Sir Alexander Binnie.

Dr. W. N. SHAW congratulated the Author upon the magnificent collection of accurate data which formed the basis of the Paper. He did not know that there could be any more fitting memorial to the late Mr. Symons, to whom every one was so much indebted for knowledge of rainfall, than the maps, which exhibited practically a résumé of the results obtained during the long period of Mr. Symons's charge of the British Rainfall Organization. The year 1899 seemed to be particularly well chosen as the year of determination of the period to which the Author gave his attention, because not only was it practically co-terminous with the rainfall-data collected by Mr. Symons, but it happened to come at the end of the Nineteenth Century, and it was only fair to the Nineteenth Century to acknowledge that it had the credit of settling the average or mean rainfall for the British Isles. The Author spoke of a mean for 70 years in words which seemed to indicate that he considered that period would in some sense furnish a true mean, as distinguished from some other less accurate mean. He did not know quite whether the Author considered that, the longer the period, the nearer to truth must the mean be. It might be so, but he did not think the proposition could be accepted without some consideration. It was, of course, a fact that 70 years corresponded with two complete Brückner cycles; and if that was why 70 years was chosen, then perhaps there might be some reason in selecting a particular period as giving a true mean in a scientific sense; but he had not discovered, either in the Paper itself or in the appended Tables, anything that conspicuously supported a variation in rainfall which was periodic in 35 years, and periodic in such a way as to make the mean for the 35 years a scientific mean in the sense in which other means were not. It was quite possible that a closer approximation to the true mean was not obtained by extending the period of observation, if the true mean was regarded as that obtained by going from zero to infinity. There was another point which Dr. Shaw.

Dr. Shaw. should limit the extent to which the mere calculation of the mean over a length of years should be carried, and that was the degree of accuracy of the instruments of measurement. In using a foot-rule, repeating measurements would not increase the degree of accuracy beyond that of the foot-rule used. The instrument for measuring rainfall was an exposed rain-gauge, and perhaps the Author could say what was the real degree of accuracy of such an instrument. In some countries, particularly where there was a good deal of precipitation in the form of snow, rain-gauges were specially guarded in order that the measure of precipitation during wind might be approximately accurate; a rain-gauge which was exposed to the wind, and not guarded, might give a measurement of rainfall some 10 per cent. or more below the actual amount of rain measured in a guarded gauge; consequently, he presumed that without special guards the rainfall instruments did not reach an accuracy of 1 per cent. In England he believed guarded gauges were not used. Dr. Buchan had suggested that, in order to eliminate the effects of the wind, a rain-gauge should be put in a hole, so that its rim did not come above the surface of the ground; also, that there should be netting over the top of the gauge. He was not certain that, even in Scotland, gauges were guarded in that particular way; and in England he had seen no gauges specially guarded to protect the rainfall from the influence of the wind. At Rothamsted, where very careful measurements of rain had been made for 25 years, there were three gauges, a 5-inch, an 8-inch, and what was called a "one-thousandth-of-an-acre" gauge; those three gauges gave different measurements. The one-thousandth-of-an-acre gauge gave the most, the 5-inch gauge the next, and the 8-inch gauge the least. The difference between the 5-inch gauge and the one-thousandth-of-an-acre gauge was about 1 inch in 27 inches in ordinary years. The least difference in the 5-year averages was a difference of 2 per cent. in the wettest group of years: it was 4 per cent. in the period of greatest difference. The situation was extremely open, and he could not imagine an exposure of gauges for comparison under more favourable conditions; consequently, he gathered that, under the best circumstances, different gauges might differ to the extent of 2 to 4 per cent. It was unnecessary to refer the differences to any want of judgment or any want of accuracy in the manufacture of the gauges: he was afraid they must be attributed to the weather. Therefore it seemed to him that when rainfall-averages were obtained to an accuracy of

2 to 3 per cent., that was about as much as could be expected with the present instruments. It was unnecessary to go farther; and he congratulated the Author on putting on a truly experimental basis averages which agreed with the averages of 70 years within 2 per cent., and represented, with all the accuracy possible, the rainfall of the British Isles. For some reason, probably habit, a year was always taken as the time-unit of rainfall. He did not think that it really represented, either for practical or for scientific purposes, the most satisfactory unit that could be chosen. For practical purposes, of course, the summer rainfall was in many ways of very different value from the winter rainfall; but in the Institution of Civil Engineers he would not presume to suggest in what way the measurements should be altered, in order to give a more effective representation of rainfall for engineering purposes. The figures in the Tables appended to the Paper were a little distracting. In the comparison of the various averages for different parts of the country, they showed considerable irregularities. It was quite possible that if the irregularities due to summer thunder-storms were eliminated from the information, the arrangement would appear much more regular. Dr. Shaw.

Mr. GEORGE F. DEACON considered the Paper to be an excellent compilation of statistics, but thought its title showed that its scope was too broad to be of much utility to engineers. He trusted that the Author would at some future time, and possibly also in his reply, help the engineer with information relating to such details as, for example, the disposition of rain-gauges, and the estimation of mean rainfall upon those limited areas with which the hydraulic engineer was concerned. The Author said a good deal about the disposition of rain-gauges over the whole area of England, Scotland and Ireland, but it was desirable to know something about smaller areas, because on those smaller areas it was found that the deviations from the mean were much larger than the Author had stated them to be for the British Isles as a whole. He had taken a number of standard gauges quite at random, and he found that in No. 1 the deviation of the driest year below the mean was 41·2 per cent.; in No. 2, 40·2 per cent.; in No. 3, 39 per cent.; in No. 4, 39·5 per cent.; in No. 5, 36·4 per cent.; and in No. 6, 35·5 per cent.; as compared with 23 per cent. shown upon the Author's table at p. 24 to be the mean for the British Islands. The reasons for this were perfectly well-known; but the effect of reducing a rainfall-area in increasing the deviation from the mean had not been reduced to any law. It had Mr. Deacon.

Mr. Deacon. frequently been stated without any reference to actual areas, that the minimum year was about 33 per cent. less than the mean; but the Author showed that for England it was 26 per cent., and for the whole of the British Isles 23 per cent.; while for small areas it was certainly a great deal higher than 33 per cent., and that was a most important element in coming to proper conclusions with respect to the ultimate yield of reservoirs. As a rule, in relation to reservoirs, the average was taken of the three driest years; and for a long time it had been stated that the minimum yield of three dry years was 80 per cent. of the mean. Now it was found that it was sometimes a great deal less. The error in the first instance had arisen from the application of general averages and general minima to detailed averages and detailed minima. Another matter on which the Author might give information was the position of gauges at a particular water-shed. Most engineers had formed their own conclusions, and many had, no doubt, read what Mr. Symons and other meteorologists had written on the subject; but there still remained a great deal of information which had not been fully published, and which only those could appreciate who went into mountain districts, and had occasion to fix gauges in such places and observe their results over long periods. They often felt astonished by what at first appeared to be the incongruity of those results. He hoped the subject would be brought before the Institution again at some future date.

Mr. Archibald. Mr. E. Douglas Archibald congratulated the Author on his Paper, and hoped it would be followed by one dealing more particularly with the aspects of the question which were mainly interesting to engineers; for instance, the rate of fall at certain times, the question of evaporation, and the way in which water drained off certain watersheds. In the discussion on a previous Paper, by Sir Alexander Binnie, a suggestion had been made that sometimes the arithmetical mean was not the best mean to take; and he thought that if an attempt were made to apply the geometrical mean, the causes of some of the discrepancies which existed might be discovered. For instance, with regard to the smaller number of years of high rainfall as compared with those of low rainfall, it was quite conceivable that in some years a wet current blew over the country which did not blow in other years, its place being taken by another current which was correspondingly dry. Consequently, if x were taken to represent the actual true mean, and in one year it was supposed that by the action of this wet current it was doubled to $2x$, and that in another year it was halved to $\frac{1}{2}x$

by the absence of the wet current and the presence of a dry one, the arithmetical mean between those two would not give the result desired, while the geometrical mean would. Consequently, it seemed possible that the application of the geometrical mean might be of advantage. With regard to the 30-year period, he wished the Author had gone a step farther and taken 35 years. Sir Alexander Binnie had shown in his Paper that 35 years gave a better result than 30, 40, or 50 years, because the variations from the mean were less for 35 years than they were for succeeding years. In the case of nine stations on the Continent, the variation was distinctly less; for the 35 years it was 0·94, for 40 years 1·16, for 45 years 1·35, and so on; so that the 35-year period, even without any reference to theory, appeared to be the best eliminant. But in addition there was the fact that Brückner had already shown that, in all parts of the world, the 35-year period held, in rainfall, in barometric pressure, and in other meteorological variants. The 35-year period also embraced approximately three sun-spot periods. Consequently it not only eliminated the Brückner variation, but also three sun-spot periods. Although just lately the 30 years had been a little nearer the mean, this was simply due to a temporary variation in the length of the Brückner period; the long rainfalls recorded at Padua, Klagenfurt and Milan, all showed the 35-year period. Dr. Julius Hann had traced it in those records, and it certainly ought to be generally adopted as the best period. In Table I. it would be an advantage if the Author would shift the columns back. The mean for any period of years ought to be placed opposite the middle date of that period; but in Table I., taking the Boston records as an example, opposite 1839 was placed the mean of the preceding 10 years, namely, −1. If that −1 were shifted back 5 years it would be in its right place. In the next column the 3·3 ought to be shifted back 10 years, and in the next column the −0·7 ought to be shifted back 15 years, and so on. If that were done, each of those figures would correspond with the period which it represented. With regard to total rainfall, he thought it would surprise many people to hear that the actual average annual rainfall given by the Author for England, namely 39·24 inches, was almost exactly the same as the average for the whole of India, which was 39·55 inches. It was usually believed that tropical countries had much heavier rainfall than England, but it appeared that the difference was really very small; and this result upset the conclusion come to by Mr. H. F. Blanford some years ago, that not many places outside the tropics had as large a rainfall as India. The variations from the mean in

Mr. Archibald.

Mr. Archibald. India were also very similar to the variations in the British Isles. The maximum found by the Author was 53 per cent. above the average and the minimum was 30 per cent. below. In India the maximum was 48 per cent. above and the minimum 28 per cent. below the average. Another curious result of the Author's investigation was that in Figs. 5 and 6, Plate 3, it would be found that the year 1874 was the minimum year for eight places in the east of England, but a maximum year for six places in the north-west of Scotland; while 1898 was the minimum year for ten places in the east of England and also the maximum for four places in the north-west of Scotland. Therefore it was possible that one portion of the country might have its minimum year while the other part was having its maximum.

Mr. Hawksley. Mr. CHARLES HAWKSLEY, Past-President, pointed out that, in determining the length of period to be taken, it was desirable to include an equal number of wet cycles and dry cycles; though when records extended over so long a period as 40 years, the inclusion of one more wet cycle than dry cycle or one more dry cycle than wet cycle was not of much consequence, because the difference was divided over so large a number of years. With regard to the variation in the records in small areas, he had noticed that in areas so small as 5,000 or 10,000 acres, in which a considerable number of rain-gauges had been placed in different positions on both sides of a valley, and at various altitudes, the several gauges gave very different results. Therefore in determining the rainfall over even a small area it was desirable to have at least three or four gauges. Otherwise it might happen that a gauge was placed in a situation which caused it to give a result differing very considerably from the average rainfall over the whole area.

Mr. Cooper Mr. C. H. COOPER regarded the subject from the point of view of flooding—a matter which had come very much under his notice during the year 1903. On 30th May he had passed over the River Wandle at 3.30 P.M., when it was practically empty; but 2 hours later it was running in full flood. At that moment a large part of the valley had had no rain whatever, whereas at other stations the fall had been very heavy. At Beddington Mr. Bayard registered no less than 2½ inches per hour. A little distance away considerably more rain had fallen, but owing to the absence of self-registering rain-gauges, there was no record of this fall except that 3·67 inches fell in 24 hours. It would be very useful if self-registering rain-gauges could be established more generally throughout the country. It was almost impossible to make, from the present returns, a satisfactory estimate of what quantity of water would have to be dealt with in any drainage-

area; whereas, if self-registering rain-gauges were established, that information would be available.[1] Mr. Cooper.

Mr. W. B. Tripp remarked that in the seventies he had been much struck with the succession of wet and dry periods he had observed in South Africa, and he had tried to work out the variations of average annual rainfall over the globe; but he had soon discovered that the records needed for the solution of the problem were neither numerous enough nor sufficiently long-continued. The best-recorded portion of the world was the British Isles, and after that Europe. Italy had the oldest and the longest records. He had divided the hemispheres of the globe into quadrants, and as far as possible had taken the averages in the different quadrants. He had found that, in the quadrant which included the British Isles and Europe, the cycle was 33 years, as far as could be judged by choosing the records of stations distributed as evenly as possible, in the same manner as the Author had worked. The records did not go back far enough in a previous period. The two culminations of the wet years occurred in 1838 or 1839, and in 1872, a difference of about 33 years. The middle of the dry period in the fifties occurred in 1854, which was a very dry year, and the minimum year after 1872 was 1887, which again was an interval of 33 years. As the Author remarked, the most difficult thing was to find a large tract of country over which the average rainfall was at all similar. Even in the diagrams, as had been pointed out by Mr. Archibald, the east of England might be dry while the north-west of Scotland was wet, or vice versa. By taking records over a large area and averaging them, the most persistent wet periods were brought out; and it was thus that he had obtained the two dates 1838–1839 and 1872. The seventies were marked by wet years in South Africa as well as in many other parts of the globe. The most remarkable wet year he had been able to discover was 1872. At a vast number of stations in Europe, extending from Upsala in Sweden, down to the South of Europe near Gibraltar, that year was very wet; indeed, he had been unable to find any other year so consistently wet. It therefore appeared to him that 1872 would be a very suitable year from which to reckon cycles, regarding it as being the culmination of a wet cycle. Probably 1872 was wet farther south than Europe, because in that year Stanley was on his way home after finding Livingstone, and had to struggle with tremendous floods on the Mr. Tripp.

[1] Mr. Cooper handed in Tables showing the average annual rainfall at Wimbledon for the years 1854–1899, and the average monthly rainfall for 1888–1903; also a list of excessive falls in a single month since 1853. These documents are filed in the Library of the Institution.—Sec. Inst. C.E.

Mr. Tripp. Congo; while over the whole of the Cape Colony that year was more consistently wet than any year that preceded it, so far as the records went. There would, of course, be many serious gaps for which no records existed; but as far as the records went, 1872 seemed to be the most remarkable of wet years.

Dr. Scott. Dr. ROBERT H. SCOTT said that his friend Professor Mascart, the head of the French Meteorological Service, had remarked to him that meteorology meant money. Mr. Deacon had expressed regret that particular areas were not more closely planted with rain-gauges, so that more accurate records might be obtained; but was Mr. Deacon prepared to pay for the instruments? If he was prepared to put down a few thousand pounds, his demand could be met. In the same way Mr. Cooper had talked about self-recording rain-gauges. It was difficult to get gentlemen living in the country to pay 5*s.* for an ordinary rain-gauge; and it would be still more difficult to get them to pay for a self-recording rain-gauge. People who cried for self-recording rain-gauges were simply children crying for the moon. It was merely a question of money; and there was no use calling on the Author to do it, unless money was given him for the purpose. He had thorough confidence in the way in which the Author was working at the subject, and he would suggest that members of the Institution should not ask for what was impossible.

Mr. Hopkinson. Mr. JOHN HOPKINSON observed that he had worked at the subject in rather a different way from the Author. It seemed to him that two questions arose, namely, had the Author taken a sufficient number of stations, and was the length of time sufficient in order to get the mean rainfall? He thought the 138 gauges which the Author had taken for England would be utterly inadequate for giving any idea of the mean rainfall, were they not admirably selected for that purpose. From the results of his own investigation he could say that they were well selected and did give a good result. With regard to the 30-year period, in the abstract he thought it was not long enough; but the Author had selected an excellent period for showing the mean, namely, the 30 years ending with 1899. He would confine his remarks entirely to England, for which some years ago he had computed the mean rainfall for various periods ending with 1890. He had found that for the 10 years 1881–1890 he could get for each county in England one gauge for every 100 square miles, which gave 502 stations. He had selected stations as equably distributed as he could, where there was a possibility of selection. In some counties there was no such possibility, as he had only just been able to get the proper number to represent the area of the county. The mean rainfall for those

10 years, 1881–1890 was 31·76 inches. In dividing the area he had considered each riding of Yorkshire as a separate county, giving the proper proportion of stations to each riding instead of taking Yorkshire as a whole. These 10 years were utterly inadequate for giving correct results and he had taken the 25 years 1866–1890, with 102 stations out of the 502, and had calculated the rainfall for the 25 years, and also the rainfall at the same stations for the 10 years 1881–1890, and by proportion it had been found that the corrected mean for the 25 years was 33·45 inches. For the 40 years 1861–1900 he could find only 50 stations with a continuous record, so distributed as to give the proper proportion for each of four divisions of the English counties—northern, midland, south-eastern, and south-western. For the whole of England there was one gauge to every 1,000 square miles, selected as equably distributed as possible; for the northern counties 18 gauges, for the midland, 11; for the south-eastern, 10, and for the south-western, 11. For these 40 years, the mean rainfall at the 50 stations was 31·54 inches, and for the 25 years 1866–1890 at the same stations 32·55 inches, and by proportion that gave for the whole of the 502 stations as nearly as possible, supposing they had been continued throughout the 40 years, a rainfall of 32·41 inches. Carrying the calculation back to the year 1841, out of the 502 stations he had been able to find only 15 with a continuous record for 60 years, giving a mean rainfall of 33·87 inches, and, by proportion for the 60 years ending 1900, 32·28 inches. Only a few records went back beyond the 60 years, and he had not access to the details; but the Author had; and therefore he had taken the Author's percentage, and found that the correct mean for the 70 years would be as nearly as possible 32½ inches. In this way a result was obtained midway between the result given by the stations and the result given by the map; but the 33 inches which the Author gave for the mean annual rainfall of England had to be reduced for the 70 years by a small amount, which brought the mean for the 70 years 1830–1899 to 32·60 inches. That, he thought, was as near an agreement as could be expected to be arrived at by totally different methods, an entirely different selection of stations, and a slightly different period, 1830–1899, against 1831–1900. He mentioned that fact in order to show how well the Author had selected his stations and his period. There were several other questions of great interest. He had worked out the following results with regard to certain periods of the wettest and driest years. He had taken the years ending in 5 and ending in 0, and had found that for the 60 years 1841–1900 the driest 5 years gave 7 per cent. below the mean, the driest 10 Mr. Hopkinson.

Mr. Hopkinson. years 5 per cent., the driest 20 years 3 per cent., the driest 30 years 1·5 per cent., and the driest 40 years 0·5 per cent., below the mean. The wettest 5 years gave 12·5 per cent. above the mean, the wettest 10 years 9 per cent., the wettest 20 years 6 per cent., the wettest 30 years 3 per cent., and the wettest 40 years 1 per cent., above the mean. The 40 years 1861–1900 gave the nearest result to that of the whole 60 years, namely, 0·56 per cent. above the mean. The 40 years 1851–1890 gave practically the same divergence below the mean, namely, 0·63 per cent. The foregoing figures applied to the whole of England, worked out for the 502 stations, and showed the decided advantage of a 40-year period over a 30-year period. With regard to the county of Hertford, in which Mr. Hopkinson had been making observations and compiling returns of the rainfall for nearly 30 years, the Author had taken two stations in Hertfordshire, one at Gorhambury, St. Albans, representing the catchment-basin of the Colne, the other at Much Hadham, in the catchment-basin of the Lea. It happened that the station which represented the catchment-basin of the Colne had a rainfall 0·5 inch above the mean for the Colne Valley, and that the station which represented the catchment-basin of the Lea had a rainfall 1 inch above the mean for the Lea Valley, in this case above the mean of fifteen stations in this area for 20 years: which he thought was a sufficient number of stations and a sufficient length of time to show the relation which the rainfall at any one station bore to the average rainfall in the watershed of the Lea. The result was, so far as he could tell from the small scale of the map, that the Author appeared to have drawn his 25-inch line a little too far to the north; the basin of the Lea should be brought within the area under 25 inches, instead of being placed, as it appeared to be, in the area above 25 inches. It was only a small point, but it showed that it would not do to rely upon a single station in such an area, if that station happened to be one having a rainfall departing rather largely from the mean of the whole of the gauges in the area. With regard to composite records, that was, records made up from gauges within a short distance of each other, he wished to give some figures obtained from Nash Mills and Apsley Mills. At these stations the gauges were within ½ mile of each other; they were between the two mills in the same valley, and had very nearly the same elevation. It would seem to be impossible that the record of one gauge over a series of years could differ much from the record of the other gauge. Yet, what was found? The Apsley Mills record commenced with the year 1890; the Nash Mills record ended with the year 1898, so that they ran side by side for

9 years. For the first 6 years of the period the difference between the two gauges was only 0·05 inch (Nash Mills 26·40, Apsley Mills 26·45). There was also but little difference in the number of wet days, the average being 165 at Nash Mills, and 162 at Apsley Mills. But for the next 3 years, 1896–1898, the Nash Mills gauge gave nearly 3 inches less rain per annum than the Apsley Mills gauge, and an average of 11½ wet days less. Supposing the Nash Mills gauge had been discontinued in the year 1895, it would have been said that it was perfectly justifiable to continue the records with those of the new Apsley Mills gauge, the mean difference in 6 years of 0·05 inch being inappreciable. But if the Apsley Mills gauge had only been commenced in the year 1896, it would have been said that the records could not be treated as continuous, as there was a difference of nearly 3 inches. One gauge must be wrong, and the question was, which? He had compared the rainfall with that in the surrounding area, and had found that the Nash Mills gauge showed a decided defect in those 3 years from the relation which it had showed up to that time. He had pointed this out to Sir John Evans, in the last year of the three, and Sir John had told him, that the Nash Mills gauge was to be given up, admitting that it had become unreliable. He did not wish to throw doubt upon the accuracy of the whole of the valuable series—Nash Mills was one of the classical series of rainfall-records of over 60 years' duration—he merely wished to point out what he thought was important, namely, that the rainfall given by the Nash Mills gauge for the three years 1896, 1897, and 1898, must be neglected altogether as unreliable, and the record be considered as terminating with the year 1895. If that were done, it did not matter where the record of the two gauges was broken, between 1890 and 1895. Mr. Hopkinson.

The PRESIDENT asked whether there had been any change in the surrounding conditions. The President.

Mr. HOPKINSON was not aware of any. In the year 1890 the Nash Mills gauge burst from frost; but it was repaired and he could not say what was the reason of the difference. In that connection he might mention an experience he had had with regard to a gauge at Watford. A return had been supplied to him which he had been unable to accept for publication in his rainfall-report for the Hertfordshire National History Society, as it showed too great a discrepancy from the records of other gauges in the neighbourhood. He had suggested that the observer did not read the gauge daily, but he had been informed that that was not so, and that the Mr. Hopkinson.

Mr. Hopkinson. record was correctly taken. Ultimately it had been discovered that the gauge leaked.

Sir Guilford Molesworth. Sir GUILFORD MOLESWORTH, K.C.I.E., Vice-President, remarked that, as India had been referred to, he might say that the question of rainfall in that country had occupied a good deal of his attention. Attempts had been made to obtain formulas for the discharge of Indian rivers, which had perhaps the largest discharge in the world, especially the Ganges and the Brahmaputra; but all endeavours made to obtain anything like formulas, such as those of Dickens, Ryves, Burge and others, were of little avail. They might be applicable to very small areas, but they were utterly useless for general purposes. As might be imagined, the problem was one of great difficulty, because the rainfall varied between about 2½ inches per annum, in Karachi and in the parts about the Rann of Kutch, and 600 inches to 800 inches in Cherra Punji. The Meteorological Department actually had a record of upwards of 1,000 inches. Without throwing doubt on the record of the department, the director had informed him that that fall occurred before the Meteorological Department took over the station. Yet, 30 miles from Cherra Punji the rainfall averaged about 70 inches. Air saturated with moisture travelled over the low, hot country and met an obstacle rising suddenly from nearly sea-level to a height of, perhaps, 5,000 to 6,000 feet. The moisture was discharged like water squeezed from a sponge, and 30 miles behind the hills the rainfall was a mere nothing. Formulas for discharge were generally based upon the area of the catchment ground, etc. He had with great difficulty crossed the Gugger on an elephant in the rains when the river was nearly ½ mile wide; but that river never reached the sea; it wandered through hot districts and was lost altogether. Therefore, for practical purposes, it was almost impossible in India to deduce from statistics of rainfall any general formula to serve as a reliable guide to the engineer.

Mr. Marriott. Mr. WILLIAM MARRIOTT had been more than ever impressed during the discussion with the value of the work carried on for so many years by the late Mr. Symons. The immense amount of statistical information gathered together by Mr. Symons was now being discussed by the Author, who brought to bear upon the subject geographical knowledge, and was able to discuss the data in a way that would render his work extremely valuable. Some remarks had been made as to why a longer period and more stations had not been taken, but it should not be forgotten that in the earlier years the stations had not existed; rain-gauges had been neither

plentiful nor used under the most favourable conditions. He had known rain-gauges placed under trees where they would by no means get the proper amount of rainfall. At the Royal Observatory, Greenwich, rainfalls were quoted from about 1815. The Greenwich authorities, like the Indian authorities, did not acknowledge reliable data farther back than 1840 or 1841. Before that date the rain-gauge was on a wall over a library, about 22 feet above the ground. When Mr. Glaisher wanted to get a long series of observations for about 30 years before the period covered by the Author's work, he had had to discover the difference between the gauge started in 1840 and the earlier gauge 22 feet above the ground, and to apply a correction to the earlier records, so as to adjust them to the equivalent reading of the gauge near the ground. That want of uniformity was one of the great difficulties Mr. Symons had had to contend with in the early days. If all the rain-gauges of which the Author had exhibited diagrams were properly placed, and did not leak, they would give practically the same results. But gauges might also be affected by change of surroundings. Like Dr. Scott, he was in the habit of inspecting rain-gauges at the stations of the Royal Meteorological Society, and he had sometimes found that in course of years there had been a change; trees had grown, buildings had been erected, and other things had occurred, which had interfered with the exposure of the gauges. At Rousdon Observatory in Devon, the late Sir Cuthbert Peek had a fine equipment about 1885. It was then a new place where trees and shrubs had been planted, and these grew apace, so that in the course of a few years the exposure there became very confined and the instrument had to be shifted into a more open place. It was the same with the gauge in his own garden; a few years ago there were no houses round about, but the London builder had now erected some, and the trees planted in neighbouring gardens had grown up, and he had therefore had a second gauge placed in another part of the garden. In the first year the two gauges had agreed every day except two, which happened to be snowy days; but in the next year there had been a falling off in the old gauge; and since then there had been a considerable falling off, showing that the trees had interfered greatly with the exposure. The differences observed in the records of gauges placed in different positions on the same watershed, which had been alluded to by Mr. Hawksley, was due to the influence of the wind. A very interesting case was that of the rainfall at Seathwaite. At Seathwaite and Sty Head was found practically the heaviest rainfall in the British Isles.

Mr. Marriott.

Mr. Marriott. Seathwaite was at the end of Borrowdale about 8 or 9 miles south of Keswick, about a mile from the Sty Head pass, which rose to about 1,200 feet and then went down into Wastdale on the other side. To the south was Scawfell. The general direction of the wind was from south to west, and as it came from the Irish Sea along the low ground by Wastdale, it was forced up rapidly in a confined space to a great height; there was consequently great reduction in temperature, and the moisture which the air contained was deposited as rain. Measuring the velocity of the wind by means of the anemometer at Fleetwood, he had found that the greater the velocity of wind in a gale the heavier was the rainfall at Seathwaite, which reached even 6 inches of rain in 24 hours. Again, on those days when it was so wet at Seathwaite, the dry-bulb thermometer showed the air at Seathwaite to be comparatively drier than at other places. The air, being driven up, had parted with its moisture and come down on the other side of the hills drier and consequently warmer. In 1883 the Meteorological Office published "Rainfall Tables of the British Isles" for 15 years, compiled by Mr. Symons, and in 1897 for another 10 years, 1881–1890. He had gone through the summary for the latter 10 years with a view to find out something about the question of rainfall and altitude. As indicated by the maps, the rainfall was much less in the east than in the extreme west, and he had divided the country into two parts, east and west; the former including all that part of the country where the rivers flowed eastward, and the latter including districts where the flow was westward. Then he had sorted out the means under the heights of the stations above sea-level, and had found that there was a gradual increase in the rainfall with the elevation; but on the west side it was considerably more than it was on the east side, showing that the air came from the west charged with moisture, struck the high ground, parted with its moisture, and came down on the east side with less to precipitate. Such facts as those, if considered by engineers in connection with rainfall over certain watersheds, would be of great assistance.

Mr. Inwards. Mr. R. Inwards called attention to one little point which had not been touched upon. Engineers required not only rainfall-data, but, generally speaking, information as to the rainfall minus the evaporation; and where they had to examine watersheds it seemed not too much to expect that they should use not only rain-gauges but some form of percolation-gauge, which would not differ much from a filter. The records could be taken monthly and deducted from the records of the rain-gauges.

Mr. HOPKINSON added, with regard to Seathwaite, that the average rainfall there for the 30 years 1870–1899 was about 130 inches, and for the previous 10 years about 150 inches. It was curious that there should be such a difference at Seathwaite, while over the whole of the rest of England there was practically no difference between the rainfalls of these two periods. Mr. Hopkinson.

Mr. DOUGLAS ARCHIBALD said he happened to know Cherra Punji well, and the highest rainfall that had ever occurred there in one day was 40 inches, on the 12th June, 1876. The actual annual average was about 500 inches. Mr. Archibald.

The AUTHOR, in reply, remarked that it had gratified him extremely to find how closely the discussion had been kept to the substance of the Paper. He desired to repeat once more that the Paper was based on the work of his predecessors, Mr. Symons and Mr. Wallis, and all that he had done was to put together, in a way that their busy lives had not permitted them to do, some of the results which could be deduced from their collection of data. It was extremely difficult to know what should be left out, and, of course, it was only possible to include a mere fraction of the vast wealth of interest in the statistics. He looked forward, as a remote ambition, to publishing a volume of "British Rainfall," possibly larger than the annual volumes, dealing with the whole series of years from the commencement of that record, and perhaps going farther back, giving the average results and the extreme results, and discussing all the data with a comprehensiveness that would be impossible in any Paper read before a society. Sir Alexander Binnie had shown how interestingly the new discussion of the data bore out the conclusions at which he had formerly arrived, and called attention to several relations with which the Paper did not deal, as the first part of the subject had been compressed in order to give more space to the distribution, which, the Author imagined, would prove more interesting to the Institution. One of the points that Sir Alexander Binnie had made was that the average percentage excess of the wettest year over the mean in different countries of Europe and other continents was, on the whole, higher than that in the United Kingdom. There was one possible explanation which might account for that fact, at least in part, namely, that on the Continent, and he thought in the United States also, the custom was to expose the rain-gauge at a considerably greater height above ground than was usual in the British Isles. The result was to give a somewhat lower mean rainfall, because a gauge raised above the ground caught less rain than one close to the surface. On the other hand, The Author.

The Author. during very heavy falls of rain, the amount caught in calm weather in a gauge raised 20 feet or more above the ground was practically indistinguishable from that in a gauge at the ground-level. Consequently, very heavy rainfall was apt to exceed the mean much more in the case of a high gauge than in that of a gauge 1 foot above the ground. The question of high gauges was one of the most difficult to deal with, because there was no general correction that could be applied. Sometimes gauges which differed in elevation by 6 to 10 feet read practically identically; in other places gauges similarly exposed exhibited a serious discrepancy. That was one of the reasons which had induced Mr. Symons so emphatically to insist upon uniformity in the height above ground of rain-gauges used for comparative purposes. With regard to the remarks made by Dr. Shaw about the size of rain-gauges affecting the amount of catch, he had looked up the observations made at Camden Square for 23 years with an 8-inch rain-gauge, which was read daily, a 5-inch gauge which was read weekly, and an 8-inch gauge which was read monthly. They were read at those intervals in order that one might control the other. Taking the average of the 5-inch weekly gauge as 100, it was found that the 8-inch daily gauge for 23 years averaged 100·2, and the 8-inch monthly gauge for the same period averaged 99·9; so that the mean of the two was almost identical with the average of the weekly gauge. It would be quite impossible to get three independent readings to agree more closely. Not content with that, he had gone through the volume of "British Rainfall" for 1902 and had taken out the results of twenty-seven stations where there was a 5-inch gauge and also an 8-inch gauge at the same level. He had left out of account a few stations on the summits of some of the Yorkshire moors, because their results were so extremely discordant with the rest that there was obviously some local condition which entirely destroyed their value for the purpose of this comparison. These discordant gauges were all together, clustered on about 20 square miles, and the other twenty-seven gauges were scattered over the length and breadth of the British Isles. The result was that the 8-inch gauge sometimes read a little higher than the 5-inch, and sometimes a little lower. But in the whole twenty-seven one deviation cancelled the other, and the mean of them all came out so as to give for the 8-inch gauge an excess of 0·06 inch for an average rainfall of about 27 inches. That showed that there was really no uniform difference to be found between the 5-inch and the 8-inch gauges. When dealing

with larger gauges, like the $\frac{1}{1000}$-acre gauge at Rothamsted, the influence of condensation at night had to be taken into account. A heavy deposit of dew was formed on a large exposed metal surface (a smaller surface being prevented, by the warmth of the earth in which it is embedded, from becoming so cold), and all the dew formed on the collecting surface of the large gauge was collected and measured as rain. The fact that the $\frac{1}{1000}$-acre gauge at Rothamsted gave a much larger number of rainy days than the small gauges seemed to prove that it must be due to that form of precipitation, and not to rainfall. It was, however, essential to include that form of precipitation in the records of rainfall. He had selected 70 years as the period for comparing the various 30-year intervals into which it could be divided because he could not get a longer period: it was not because it had any occult relationship to cycles or anything else, but simply because it was the longest period he could get which was common to a considerable number of stations. If he could have obtained 90 years, so as to have had three consecutive periods of 30 years, he would have preferred it. The reason why 30 years had been adopted was a strictly practical one; it was to give the greatest possible number of long records that could be obtained, with the least amount of computation in order to make up the quantities. Some computation had been necessary, and had been applied when required. He would like at some future time to test strictly a 35-year periodicity. He did not doubt that it was a very important period, and might be found to have a bearing on practical questions, if it were possible to find a way to isolating the cycle from the various disturbing causes with which it was bound up. He sympathized with what Mr. Deacon had said about the Paper not being so helpful to engineers as they would like it to be; but that was because engineers were so detailed in their work. They worked with definite problems; and although those problems were often vast from the point of view of the ordinary workman who built a house, or dug a ditch, they were very small compared with the great processes of Nature; and it was necessary, in dealing with such circumscribed problems, to make a great many more detailed observations than were required for discussing the general distribution over the country as a whole. Those detailed observations had, as a rule, to be made at the time they were required; because, he was sorry to say, no human being had yet had sufficient foresight to take observations in places where they might be wanted 50 years later. Fortunately, many engineers were fully awake to the importance

The Author.

The Author. of obtaining records some considerable time before they were required; and year by year the possibility of determining accurately the rainfall of small areas was being increased. Since the time Mr. Symons commenced his work the possibility of making such determinations correctly had been very largely increased. The same remark held good with regard to the relation of the extreme years to the average, and with regard to the driest year or driest three years. These questions had to be generalized when dealing with a large area of country, and they had to be treated in detail when dealing with small areas. The placing of gauges was a matter of great importance, and he had no doubt that many of the rain-gauges which had been used on the high exposed moorlands of the country gave results which were much too low, because of the action of the wind on the gauge; and the utmost care must be taken in selecting a site not to have the gauge standing on a sky-line where there was a sweep of air from whatever quarter the wind might blow. Every gathering-ground had features peculiar to itself, so that the problem must be treated separately in each case, and not generalized upon. In the future it might be possible to generalize to some effect, but a great deal of additional information was first required. Mr. Archibald had referred in a very proper way to the objections to the use of the arithmetical mean, and the Author had often been struck by the difficulty of using arithmetical means for divergencies from the average. But that again involved a practical question. Very often the data dealt with were not sufficiently accurate to justify the application of the most exhaustive or the most satisfactory method that might be applied if the data were perfect; and it was his belief that it was quite unnecessary to require more accuracy in the treatment of figures than was required in the observations from which those figures were obtained. Mr. Archibald wished that 35 years had been taken. The Author wished he had had the 35 years to take for the general average, but it would have involved computing so many of the records for stations, supplying so many missing years in a theoretical way, that the result would have been very largely deprived of its practical value. The suggestion to shift the columns of figures in Table I, so that the mean for 10 years should occur opposite the middle of the 10 years instead of the last year, was a point where the ordinary reader had to be taken into account. It would perhaps be confusing to the ordinary reader to find the mean of 10 years opposite the fifth year instead of the tenth. But the matter might safely be left to the Secretary of the

The Author. Institution in editing the Paper. He had no objection whatever to its being done if it was likely to make the Table more useful. When Mr. Archibald compared the rainfall of England and India, he of course meant the British Isles and India; in questions of geographical distribution it was necessary to be explicit in nomenclature. With regard to Mr. Cooper's observations about wet days, that, of course, seriously complicated the treatment of individual years, because one wet day with 3 inches or 4 inches of rain might shift the totals of two years, especially if it occurred on the 31st December, and was counted by some people in one year and by others in the next. He heartily agreed with Mr. Cooper as to the importance of introducing more recording-gauges, and he regretfully agreed with Dr. Scott as to the impossibility of so doing under the present circumstances. Fortunately recording-gauges were becoming cheaper and more accurate, and he hoped that soon they would be much more largely used. Mr. Hopkinson had made certain statements that required to be set right. To begin with, he had misunderstood the method by which the maps were constructed. There were 138 selected stations given in full in the Paper, which were stations used to get an arithmetical average to compare with the averages calculated from areal measurements made on the maps; but the maps were drawn from more than 1,000 stations, as was described in the Paper. Of these 380 had perfect 30-year records, and about 700 had values computed from periods for the most part exceeding 20 years in length. He would never have attempted to draw the isohyetal lines across so large and important a county as Hertfordshire from two stations: he had used fifteen stations in that county. The lines were, in his opinion, correctly drawn, and he would be ready at any time to support their accuracy. He believed that the greater part of the basin of the Lea had an average rainfall greater than 25 inches. He gave Mr. Hopkinson full credit for being an excellent rainfall-observer and for having done much to promote the establishment and maintain the accuracy of rainfall stations in Hertfordshire; but rainfall only shared with many other branches of science a portion of Mr. Hopkinson's spare time, and although, after careful study of the matter, the Author was obliged to disagree with the methods adopted by Mr. Hopkinson in estimating the rainfall of counties, he wished to assure that gentleman that he was not oblivious to the good work done by him in Hertfordshire. He desired in conclusion to thank those who had taken part in the discussion, and the President for directing the discussion so ably, and he trusted that the records he

The Author. had brought together might prove in some way useful to engineers, even though they did not give all the information that might be desired.

The President. The PRESIDENT remarked, with regard to the determination of averages, that to those who were accustomed to deal with curved surfaces and with irregular forms, it was quite clear that no geometrical mean was to be trusted, and that the only true way, which the Author had fully appreciated, and indicated in the Paper, and which he desired to adopt if he could, was to determine accurately the surface formed by contact with the heads of all the ordinates representing rainfalls, and to obtain the average ordinate by measurement of the volume. But in default of a multitude of observations it was quite clear that could not be done. He felt sure the members were agreed that the Author had made admirable use of the material at his command, and they owed him a great debt for thus analyzing and arranging the valuable data accumulated by the late Mr. Symons.

Correspondence.

Professor Abbe. Professor CLEVELAND ABBE, of the United States Weather Bureau, observed that it certainly was a pleasure to read a memoir in the English language dealing with the distribution of rainfall for a specific, fundamental period of time. He believed that the Paper was the first memoir in which this important feature had been introduced by an English or an American writer. The interval 1870–99, chosen by the Author for his rainfall-maps, was certainly the best that could have been selected, since the accurate work of recent years was the safest foundation for study. The care shown in selecting fundamental stations, as detailed on pp. 289–300, greatly heightened confidence in the results, so that the memoir became one of the best in any language. It would have been more in accordance with the practice of the best climatologists if the Author had used the probable error, as defined by Gauss, in preference to the mean of the departures, as his index to the reliability of any given series. The study of the numerous gauges maintained by Hellmann in the experimental rainfall-field of the Meteorological Institute at Berlin showed that, owing to slight variations in the local winds at the mouths of the gauges, the differences in their catches had a range of 12 per cent.; although

they were exposed under conditions as similar as it was in any way practicable to obtain. The probable departure of any one annual rainfall from the mean of the whole was ± 6 per cent. for gauges whose mouths were 1 metre above ground. The general formula, deduced by himself[1] in 1887, showed that these probable departures would become ± 4 per cent. for gauges set at the level of the ground, or for those that were in any way properly protected from the influence of the wind on the catch of the gauge. Since very few, or practically none, of the British and American gauges were protected from the wind, it was fair to adopt 6 per cent. as the probable uncertainty, in the annual catch, due to the wind. There were also other inevitable sources of error which could easily bring the probable error up to ± 8 per cent. of any given annual rainfall. Hence the probable error for a mean of 10 years, and for the best stations would be 2 to 3 per cent., and for ordinary stations even more. These figures agreed fairly well with those given by the Author in his second Table (p. 295), since the average departures given therein must be multiplied by 0·85 in order to obtain the probable variations that were used in the Gaussian method of least squares. It was desirable that the probable error should be used by all climatologists, as it was by all astronomers and physicists; but care must be taken not to be misled by the use of the word "probable." This number was merely an index to the internal variability of the series of measure and had no bearing upon the absolute accuracy of the result, unless it could be assumed that all constant and periodic sources of error had been eliminated or removed, so that nothing but pure accident remained to be considered. The probable error was 0·85 of the average of all the departures, or 0·67 of the square root of the sum of the squares of the departures. The probability of the occurrence of a departure equal to the probable error was just one-half, so that there should be an equal number of departures respectively larger and smaller than it. A clear idea of the relative variability of British and foreign annual rainfalls could be obtained only by reducing the Author's mean departures, or average variations, to the probable variations or probable errors used by the best continental climatologists in conformity with astronomical usage. Thus, on p. 297 the means of 30 years for five stations, and for five different groups of consecutive years, gave the Professor Abbe.

[1] "Determination of the true amount of Precipitation and its bearing on Theories of Forest Influences." Bull. 7, Forestry Division, U.S. Department of Agriculture, p. 180.

Professor Abbe. probable error of any one of 30 years as 0·5 per cent., and the probable error of the mean of 30 years as 0·09 per cent. This could not be converted into inches of rainfall, since all the five stations given on p. 297 did not occur in Table III.; it was much to be desired that this Table might be enlarged by the addition of the other 89 stations having perfect 30-year records, which made up the 380 stations that formed the basis of the Author's work. This 0·09 per cent. might be compared with the probable errors given by Angot at p. 178 of his memoir on the rainfall of the Iberian peninsula. The stations in this region had probable errors varying between 0·02 per cent. and 0·05 per cent. for the 30 years 1861–90, but, of course, the absolute rainfalls to which these percentages referred were much smaller than those of Great Britain. The arrangement of Table I. became troublesome when an attempt was made to compare the rainfall for any period with that other periods symmetrical with it. He would prefer to arrange the figures more symmetrically. Thus the 1·1 opposite the end of the period 1830–49 should be placed opposite the date 1840, as that was the middle point of the series, and the mean for the 10 years 1835–44 should also be placed opposite the same date. In this arrangement the left-hand column became a column of dates rather than that of years of rainfall, and by running along any horizontal line, the departures could be compared for sets of years that were symmetrical with regard to the date on the left. He had done this for one station, Chilgrove, in the accompanying Table, and had added columns for groups of 50 years, 60 years and 70 years. Opposite the date 1865 there stood −0·9, −3·0, 0·1, 0·1, −0·3, −0·05, 0·16, which figures were the mean departures for groups of 10 years, 20 years, 30 years . . . 70 years. Apparently the last figure, 0·16, should have been 0·00 if 70 years were the fundamental period, as stated at the head of Table I. Possibly, however, in this Table, as in the charts, the 30 years 1870–99 had been chosen as the fundamental period. The Author had adopted the only allowable and proper method of making use of short series in order to fill up the gaps where long series were not available. According to Angot,[1] the reduction of a short series to what it would have been if it had occupied the whole of the fundamental period, was effected by a process of geographical and chronological interpretation, first perfected by Mr. F. Fournié in 1864, in a note on the rainfall at the stations in the upper basin of the Marne. The method was very simple, but had been sadly

[1] "Régime des pluies de la Péninsule Iberique," p. 162.

AVERAGE RAINFALL DEPARTURES FOR GROUPS OF CONSECUTIVE YEARS. Professor Abbe.

Mean Date.	10 Years.	20 Years.	30 Years.	40 Years.	50 Years.	60 Years.	70 Years.
1835·0	2·2	..	..	..	..	..	..
1836·0	0·0	..	..	..	..	..	..
1837·0	1·0	..	..	..	..	..	..
1838·0	1·3	..	..	..	..	..	..
1839·0	1·5	..	..	..	..	..	..
1840·0	0·2	1·1	..	..	..	..	..
1841·0	0·2	0·5	..	..	..	..	..
1842·0	−1·7	−1·6	..	..	..	..	..
1843·0	−2·0	1·6	..	..	..	..	..
1844·0	2·4	2·8	..	..	..	..	..
1845·0	0·0	0·7	−0·5	..	..	..	..
1846·0	1·0	0·3	0·1	..	..	..	..
1847·0	−4·3	−0·8	−1·1	..	..	..	..
1848·0	2·0	−0·2	−0·7	..	..	..	..
1849·0	3·1	−0·9	−1·1	..	..	..	..
1850·0	1·1	−1·8	−1·9	−0·6	..	..	..
1851·0	0·5	0·2	−1·2	−1·2	..	..	..
1852·0	0·0	−2·1	−1·6	−1·7	..	..	..
1853·0	1·7	−1·8	−1·3	−0·7	..	..	..
1854·0	−4·2	−2·4	−0·8	−0·9	..	..	..
1855·0	−3·6	−3·0	−1·5	−1·2	0·48	..	..
1856.0	−0·7	−1·8	−1·6	−0·9	0·58	..	..
1857·0	0·1	−1·6	−2·7	−1·3	0·22	..	..
1858·0	−5·5	−1·0	−1·3	0·1	0·64	..	..
1859·0	−7·9	−2·3	−1·7	0·3	0·56	..	..
1860·0	−7·1	2·3	−1·7	0·1	0·16	0·12	..
1861·0	−4·2	2·9	−1·2	0·7	0·32	−0·23	..
1862·0	−3·1	1·9	−1·1	0·0	0·18	−0·15	..
1863·0	−3·7	−3·0	0·8	0·5	0·08	−0·22	..
1864·0	−0·5	−4·1	−0·4	0·3	0·38	−0·58	..
1865·0	−0·9	−3·0	0·1	0·1	−0·30	−0·05	0·16
1866·0	−5·2	−2·1	0·6	0·4	−0·28	0·18	..
1867·0	−3·8	−1·7	1·5	0·6	−0·38	−0·08	..
1868·0	−0·5	−0·4	0·0	0·6	−0·52	−0·47	..
1869·0	−0·3	1·5	−0·6	−0·1	−1·00	0·37	..
1870·0	1·0	1·9	−0·2	−0·4	−0·10	−0·18	..
1871·0	0·1	1·3	0·3	−0·6	0·16	..	..
1872·0	−0·3	2·1	0·9	0·6	0·24	..	..
1873·0	4·4	2·7	0·2	−1·1	0·96	..	..
1874·0	3·6	3·1	1·2	−2·0	−0·04	..	..
1875·0	4·7	3·3	0·7	−0·4	−0·22	..	..
1876·0	7·8	1·5	−0·6	0·1	..	..	..
1877·0	8·1	2·9	0·8	0·3	..	..	..
1878·0	5·9	2·2	0·3	0·8	..	..	..
1879·0	6·4	2·1	−0·1	1·0	..	..	..
1880·0	5·6	1·5	1·8	0·6	..	..	..
1881·0	5·0	1·7	1·5	..	..	..	..
1882·0	6·0	3·1	1·4	..	..	..	..
1883·0	0·0	0·7	2·3	..	..	..	..
1884·0	0·6	0·0	1·5	..	..	..	..
1885·0	−1·7	2·3	1·1	..	..	..	..
1886·0	−4·3	2·2	..	..	..	..	..
1887·0	−2·0	2·3	..	..	..	..	..
1888·0	−4·5	1·2	..	..	..	..	..
1889·0	−6·3	0·4	..	..	..	..	..
1890·0	−1·1	−0·6	..	..	..	..	..
1891·0	−0·6	..	..	..	..	..	..
1892·0	−1·4	..	..	..	..	..	..
1893·0	2·4	..	..	..	..	..	..
1894·0	0·3	..	..	..	..	..	..
1895·0	0·4	..	..	..	..	..	..

NOTE.—The average departures are placed opposite the middle years of the respective groups.

Professor Abbe. neglected by English and American climatologists. By using this method, and by confining himself to a series of 15 years or longer, the Author had given a rainfall-map which was beyond criticism as to these important features, and which was entirely free from the harassing uncertainties that surrounded the study of a map based on a heterogenous mixture of data for different years and different exposures of gauges. Probably, in general, rainfall-records the world over were more reliable than was supposed; and the reliability of the results to be deduced from those records depended more than was realized upon the intelligence and care with which they were discussed. It would, perhaps, be impossible for any other system of rainfall-stations to present such a homogeneous mass of material as the Author had had to deal with. Certainly no one had laboured with the records and observers so faithfully as had the late Mr. G. J. Symons and Mr. Sowerby Wallis. The independence and boldness shown by the Author in plotting his rainfall-data and drawing his annual isohyetals on a blank map, without any reference whatever to the orography of the country compelled admiration. This was done also by the United States Weather Bureau for the monthly and annual rainfall-charts of the *Monthly Weather Review*; but he believed the same plan was not followed by all who constructed so-called normal rainfall-charts. Thus the Author had shown how to solve the problem of so drawing a rainfall-map that it might give some positive knowledge of the relation between the rainfall and the configuration of the ground. By discarding regions where there were no observations, although some rain must have fallen there, the Author obtained a comparison, between his rainfall-data and his topographic charts, that gave a solid foundation for some very general relations between rainfall and the physical features of the country: there was scarcely 5 per cent. of the whole area of his map for which there could be an appreciable doubt as to the location of the isohyetal lines. It was gratifying to find that the general relation between rainfall and altitude was precisely that given[1] by F. Pockels in his theoretical discussion of the subject; yet there were some apparent exceptions. As the Author said, it was impossible not to recognize that there was a definite connection between the amount of rainfall and the configuration in many places, and that often the lines of equal rainfall laid down on a blank map, traced out the lines of hill and plain on a topographic map. Still it was true that the relation between altitude and rainfall could not be the

[1] *Annalen der Physik*, 4th series, vol. iv. p. 459. (Translated in *Monthly Weather Review*, April, 1901.)

same in different portions of a territory even so small as that of the United Kingdom; because not merely the cooling of moist winds as they surmounted a range of hills, but also the horizontal distribution of wind and of land, and the breadth of the rain-bearing current had to be taken into account. For instance, in southern and northern Wales, or southern and northern Scotland, where the south-west or rain wind arrived but little impeded from the ocean, there was a fairly typical relation between rainfall and vertical movement. On the other hand, in the Lake District of England the sweep of the south-west wind was such that over the southern portion there could not be so much rain as over the northern, on account of intervening land. In fact, the southern portion was quite in the lee of northern Wales, while in the northern portion the wind piled up over itself as well as over the land, owing to the configuration of the country. The whole of the eastern half of England, Scotland, and Ireland represented both diminished winds, drier air, and descending slopes relative to a south-west wind, so that the relation there between altitude and absolute rainfall was quite different from what it was on the windward side. There was every reason to agree with the Author in his conclusion that it was hopeless to attempt to find any definite numerical relation, applicable to the whole country, between rainfall and height above sea-level. Local relations might be found for given directions of the wind, but nothing that would have a general application to all stations. An empirical relation for the whole country could of course be found by assorting the data given in Table III. according to the height of the stations, but it would not apply to other countries or to any special portion of Great Britain. Such relations had been published for other portions of the world, but they must not be applied to any country but their own. Professor Abbe.

Dr. R. BILLWILLER, of Zürich, remarked that the Author had done his work with great care, and had used the materials at hand with all necessary discrimination. As the stations which had been at work during the whole 30 years were naturally very irregularly distributed, it was strongly to be approved that in localities possessing few of them, other stations whose records covered periods varying between 30 years and 15 years had been made use of, their records being rendered applicable to the whole period by recognized methods of reduction. Even then, the distribution of the stations, as Fig. 4, Plate 3, showed, was somewhat irregular, for in the mountainous districts the stations were much more sparse than in the lowlands. Although the same was the case to a greater or less degree in all countries, he would point out that Dr. Billwiller.

Dr. Billwiller. judging from Table III.—which, of course, did not contain all the stations used—the number of stations in the British Isles placed at considerable heights above sea-level was very small. Out of the 291 stations there enumerated there were only five at altitudes of more than 1,000 feet. For this reason it was, of course, impossible to determine a relation between the rainfall and the height of the ground, and to make use of it in drawing the isohyetals. The Author had expressly avoided doing so, and had drawn these lines solely from the results of observations. Any other course would not be feasible on the small scale of the maps, which, however, would on the whole give correctly the distribution of rainfall over the country. It must not be forgotten that the influence of mountains on the rainfall made itself felt over a wide area; on the one hand, the condensation produced on moist winds by their being forced up over high ground, especially mountains along a sea-coast, began to take effect at a considerable distance; while, on the other hand, the diminution of rainfall on the leeward side affected a considerable area of country. The isohyetals of the Author's rainfall-maps not only showed, on this account, the influence of the distribution of land and water, but the course of the curves was also, without data from high stations, determined in a large measure by the vertical configuration of the land. A diagram showing the latter would be a desirable addition to the maps. For drawing accurately the distribution of rainfall in the mountain districts of England and Scotland, which undoubtedly were the regions of maximum rainfall, the materials brought forward by the Author were insufficient. In essentially mountainous countries, such as Switzerland, cartographic representation of the distribution of rainfall would be impossible without a large number of high stations. In the British Isles, where altitudes were much less, and where, on the other hand, the distribution of land and water constituted an important factor, the conditions were otherwise; and it might be expected that the Author's rainfall-maps would suffice for many practical purposes. The data of the years of maximum and minimum rainfall for each of a number of stations were of great practical utility, showing that the maxima and minima did not occur in the same year over the whole country—a result which had moreover also been found for much smaller tracts of country in other parts of the globe.

Mr. Ekholm. Mr. Nils Ekholm, of Stockholm, was glad to see so elaborate a treatise on the important subject of the Paper, which was a fine monument to the life-work of Mr. Symons. With regard to the periodicity of rainfall, from Table I. (p. 318), there seemed to be a

very marked variation with a minimum about 1865 or 1866 and a maximum about 1882–1884. Thus from the minimum to the maximum there was a time of 17½ years, and the conclusion was that the British rainfall had a 35-year period, in accordance with the results found by Brückner and W. Lockyer. The period was not quite regular, and not equally pronounced at all the five stations; nevertheless it was evident. He believed that this conclusion would be still more evident if 11-year means were calculated, in order to eliminate the influence of the sun-spot period, and if neighbouring stations were united to means. From this it might be concluded that the most convenient method for deducing true average values of rainfall would be to take 35 years or multiples of 35 years. Thus the 70 years' average used by the Author for these five stations was very convenient. With so large a number of reliable observations, it would be worth while taking a still larger scale for the map and drawing the isohyetals still closer. Especially would it be interesting to see a system of closer isohyetals along the coast. For Sweden it had been found that the quantity of rain rapidly increased from the open sea (light-house stations) to the interior, especially during the summer. It would also be very interesting to have such maps for the twelve months and the four seasons. Lastly, if the Paper were accompanied by a topographical map showing the lines of equal height above the sea-level, the study of the interesting connection between rainfall and height above sea-level would be much facilitated. And for many purposes it would be useful to indicate on this map all rivers of the British Isles, and the watershed of each river. Mr. Ekholm.

Professor JULIUS HANN, of Vienna, entirely approved of the principle upon which the Author had drawn the isohyetal lines on his rainfall-maps, which possessed a special value from the fact that they were constructed solely on the basis of observations. The relations of rainfall to the configuration of the ground which might be deduced from them were consequently in no way hypothetical, and could lay claim to considerable scientific value. It was by the labours of the late Mr. G. J. Symons and his co-workers, that such a result had been rendered attainable; for it was only by means of a close network of recording stations, carefully supervised, that the necessary materials could be obtained for constructing such maps as accompanied the Paper. The maps showing the distribution of rainfall in the driest and wettest years were of great practical and theoretical interest. As far as he was aware, such a cartographic comparison of the maximum, Professor Hann.

Professor Hann. mean and minimum rainfall, had not hitherto been made—at least, not on the Continent. The general agreement of the isohyetals in all three maps was very remarkable, and of far-reaching consequence. He was pleased to notice that the Author had determined the probable departure of the mean annual rainfall for periods of 10, 20, 30, and 40 years from the mean of 70 years, in the same way as he himself had done for Padua, Milan and Klagenfurt. The result was very favourable to England, as the following Table showed:—

AVERAGE VARIATION FROM THE MEAN.

—	10 Years.	20 Years.	30 Years.	40 Years.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
South of the Alps . . .	7·5	5·2	2·6	2·3
England	4·7	3·4	2·2	1·7

From this it appeared that, for short periods such as 10 or 20 years, the 10-year mean in England gave as close an approximation to the long-period mean as did the 20-year mean in Southern Europe.

Mr. Jebb. Mr. G. R. Jebb agreed generally with the Author's methods and conclusions. The principle adopted in the preparation of the rainfall-maps—namely, that of ignoring the physical features of the country—was perhaps, on the whole, for the reasons given by the Author, the best; although, no doubt, a map more nearly approximating to the actual rainfall in certain hilly districts, where there were no rain-gauges, could have been made by estimating the fall instead of drawing the isohyetal lines direct from one gauge to another. He was glad to see that the Author insisted on the necessity of securing a long series of observations—extending over a period of at least 30 years—before accepting any figure as the average rainfall at any particular station. But the Paper was essentially a record of facts which had been checked and sifted with more than ordinary care; it was for the engineer to interpret and apply these facts for his own purposes. For example, it did not necessarily follow that in the year of least rainfall, the least volume of water would be collected in a reservoir; this depended on, among other things, the season of the year in which the rain came, and how it came. He was sure the Author had access to records of other facts than those given in the Paper, many of which would be useful to engineers. Referring to one set only of such facts, namely, those which related to periods of

exceptional drought, he would ask if the Author could give two additional tables (1) showing the longest period of absolute drought on record at as many stations as possible, with dates; (2) showing all periods of absolute drought extending over, say, 30 days, at the same stations, with dates. If these tables could be accompanied by a few typical diagrams showing the rainfall immediately preceding and following the dry periods, the information given in them would be still more valuable. No doubt this could all be found by searching carefully through the volumes of "British Rainfall," but it would be very convenient to have it extracted and printed with the Paper. Mr. Jebb.

Mr. G. MAXWELL LAWFORD remarked that the Paper was valuable as a work of reference, not only to water-engineers, to whom records of minimum rainfall were essential, but to the sewerage-engineer who had to provide for the rapid removal of the rain falling in cities and towns, and to whom, therefore, maximum rainfall was of paramount importance. Rainfall was very variable; and frequently, while the water-engineer on the uplands was studying drought and praying for rain, his municipal colleague might be trying to cope with 1 inch per hour and despairing as to the rival merits of the combined and separate systems. He considered that the maps of minimum and maximum rainfall were of equal importance, inasmuch as in the one case the water-engineer could estimate for deficiencies, and, in the other, the sewerage-engineer could gauge the possible surplus for which he would have to make provision. Suggestions had lately been made by Mr. E. P. Hill, M. Inst. C.E., as to practical methods of obtaining and keeping up records such as those given in the Paper, together with others relating to the yield or flow off of the natural drainage-areas. Mr. Lawford was afraid, however, that such aims would be found difficult to realize, on account of the strong objection existing to anything in the shape of additional taxation which would benefit posterity and not the present generation. A few years ago Mr. Reginald E. Middleton, M. Inst. C.E., had advocated[1] making sanitary districts coterminous with watershed areas in place of the existing boundaries, which were primarily those of the counties and secondarily those of the civil parishes. If this proposal should ever become effective—and it certainly had much to commend it from the engineer's point of view—that would obviously be the time to inaugurate Mr. Hill's proposals, as there would be no difficulty in establishing gauging- Mr. Lawford.

[1] Journal of the Sanitary Institute, 1898, p. 265.

Mr. Lawford. stations under the supervision of the officer appointed to each district by the public authority.

Prof. Mohn. Professor H. MOHN, of the Norwegian Meteorological Institute, considered the manner in which the Author has treated the subject to be the right one. He forwarded a copy of the latest rain-chart[1] drawn for Norway and Sweden, which showed the great influence of mountains on the distribution of rainfall. Maximum and minimum years showed a distribution congruent with the mean.

Mr. Paterson. Mr. MALCOLM PATERSON remarked that, although the relations of the mean and the two extremes of rainfall could be ascertained approximately with the existing recording-machinery, yet such machinery could not give the actual volume of rainfall over the country; nor, in many important cases, over smaller areas. He had inspected gauges in many catchment-areas, and had often found a want of scientific method in their distribution and supervision. Recently he had been engaged in opposition to a scheme for appropriating a mountain area of 16,000 acres, shaped like a broad pear, and rising from 500 feet to 1,800 feet above sea-level. Four gauges were fixed at the lower and narrower end of the area at an average height of 750 feet, and one only at the higher and broader end, and even this was nearly 400 feet below the highest point of the ridge, which had a mean level of over 1,450 feet, and a length of 12 miles. This disposition was exactly the reverse of what it should be, if the intention was to record the facts. Generally speaking, gauges should be equidistant. In the case in question, by adopting the deductive method practised by the late Mr. Symons, which had been the best thing open to him, and by assuming other gauges to be properly disposed, he had arrived at a mean rainfall 10 inches in excess of that recorded by the defectively placed gauges. Further, he had found that the gauges were in the hands of farmers, and had been unprotected, during the greater part of their existence, from horses, cattle and sheep, one observer informing him that he had often found his gauge kicked over. In nearly all cases the gauges were close to the farmsteads, where stock mostly fed. Two of the gauges had been moved 5 years previously; one shifted ½-mile farther down the valley and lowered about 35 feet, and the other shifted more than 1 mile down the valley and lowered 86 feet. The rainfall-tables contained no reference to these important changes. The gauges were on a catchment-area not appropriated, but intended to be so. This might possibly explain the haphazard methods, which reduced

[1] This chart has been placed in the Library of the Institution.—SEC. INST. C.E.

the fair flow of compensation-water, and vitiated the returns over an important area for a long time to come. But in dealing generally with British rainfall, no experienced engineer could regard the means as fitted for the end; they were not scientific, as no one knew better than the Author of this carefully reasoned Paper. What the country needed was a national department of meteorology, in the proper sense of the term. It was discreditable that the nation which could afford free schools, unsought, could find no money for the observation of its rainfall and rivers. A modest sum would suffice. Perhaps also, it was a reflection on a powerful body like the Institution that no organized pressure, persistently maintained to this end, had been applied to the Government, ever since the time of the River Pollution Commissions. It appeared to him that all observers and all gauges should be under a single and impartial control, the observers being trained and responsible men. Mr. Paterson.

Mr. E. KILBURN SCOTT, having had occasion to investigate the rainfall in the Snowdon district of North Wales, in connection with an electric power scheme, had been surprised to find how high and well-sustained was the average rainfall there. Indeed it would appear that Snowdon could claim to be the wettest spot in Europe, its estimated average for the last 10 years being over 190 inches, as against 170 inches for the Sty in Cumberland. The figures given in "British Rainfall" for 1901 were:— Mr. Scott.

	Inches.
Snowdon (Llydaw) 1,450 feet	169·50
„ (Glaslyn) 2,500 „	186·70

and for 1900—

	Inches.
Snowdon (Llydaw) 1,450 feet	193·50
„ (Cwm Glas) 2,200 „	173·60

For the year 1903 the rainfall at Snowdon might be taken as being over 258 inches. The wettest actual record at the Sty was 244 inches, and the dryest 99 inches. Mr. R. Gethin Jones, who had been taking the Snowdon records since 1898, had recorded nearly 7 inches of rain in the 22 hours between 11 p.m. on the 14th, and 9 p.m. on the 15th August, 1903. At Glaslyn there would probably be a couple of inches more. Again, between 1 p.m. on the 8th September and 12 noon on the 11th the Glaslyn gauge had registered 9·42 inches. The reasons for the high rainfall on Snowdon appeared to be that it was near to the track of the Atlantic depressions, and was surrounded on the south and north-west by low-level valleys running down to the sea, and along which the atmospheric moisture was carried

Mr. Scott. to the base of the mountain. The mountain rose suddenly from that side and when the wind blew from any wet point the moist air was driven up on to the high ground where the moisture was suddenly condensed, the bulk of it being discharged in the form of rain or snow on the sheltered side, namely at Cwm Llydaw. An interesting feature from the point of view of power purposes was that the wettest period of the year was in the autumn, and that in spring the average supply of water available from Lake Llydaw was, to a large extent, maintained by the melting snow. The rainfall area was chiefly rock, so that what rain did fall found its way into Lakes Glaslyn, Llydaw, etc.

Dr. Snellen. Dr. MAURITS SNELLEN, of the Royal Dutch Meteorological Institute, observed that a particular difficulty in deriving general results from a number of rainfall-observations lay in their unequal distribution in regard to both space and time, and the conscientious manner in which the Author dealt with this difficulty was very interesting and instructive. It might have been an advantage if an example had been given of the manner in which a short series of observations could be completed by means of records from two or three neighbouring stations, by publishing the whole calculation for a single station. The maps, not only for mean rainfall but also for the extremes, were very clear and were discussed in an exhaustive manner. The whole, as a work of much labour and patience and great skill, completed, in a happy way, the work of Dr. Buchan and the late Mr. G. J. Symons.

The Author. The AUTHOR, in reply, felt that the Correspondence added greatly to any value the Paper might possess in itself. He highly valued expressions of approval of the eminent foreign meteorologists who had contributed to it, and felt much encouraged by their good opinion. He fully agreed that the various tables and maps which were desiderated by the correspondents would be most desirable additions; but to follow out all the suggestions which had been made would involve the preparation, not of a Paper, but of a volume on rainfall. He felt that the maps were only first approximations to what rainfall-maps ought to be, and he was resolved to continue to work at the subject, not despairing of being able to extend and improve upon what had been done. The discussion and correspondence had laid down several lines along which he hoped to advance. With regard to Professor Cleveland Abbe's able discussion of the departures from the mean of various periods, the Author thought that the difference of 0·16 per cent. was so small as to be practically negligible. It represented less than 0·1

The Author.

inch of rain, and no one could hope to determine the rainfall of a year to a much closer approximation than 0·5 inch. He felt that it was straining the data unduly to subject them to comparisons involving the second place of decimals in a percentage. The percentages in Table I. were, as stated, related to the 70 years' mean and not to the mean of 30 years. The Author fully agreed with Dr. Billwiller that there were far too few observations at stations above the level of 1,000 feet; but their number was increasing every year, and it should ultimately be possible to arrive at useful results regarding them. Mr. Paterson had touched on a very serious defect in the system of rainfall-observations; but the Author was not without hope that the prominence given to this discussion would lead to a general improvement of waterworks-gauges. He believed that the majority of the gauges set up by waterworks-engineers were good instruments placed in appropriate sites; but he knew of some which were defective in construction, badly placed, and under the charge of observers who might not realize the importance of their trust. He never hesitated to express his opinions of such gauges when he saw them, and was always ready to supply instructions for accurate observing to every one who applied to him. The country, he need hardly remind the Institution, had a national department of meteorology; but as the constitution of that body had recently been reconsidered by a Treasury Committee, which has not yet reported, the present was not a suitable time for discussing the matter. He would only say that Mr. Symons had considered that to place the Rainfall Organization under official auspices would not necessarily increase its efficiency, while it might tend to check the enthusiasm of amateur observers. The Author had not gone so fully into the rainfall of Snowdonia as to be in a position to express an opinion on the very high average value which Mr. Scott attributed to that undoubtedly wet region; and, of course, he had not been able in his Paper to deal with the returns of 1903. The figures quoted were remarkable, but they were for individual years, and must not be taken as representing average conditions.

1 December, 1903.

Sir WILLIAM H. WHITE, K.C.B., D.Sc., LL.D., F.R.S., President, in the Chair.

THE PRESIDENT said it was with the deepest regret that he had officially to inform the members of the death of their dear friend Sir Frederick Bramwell, who had died at 9 o'clock on the previous evening, after a short illness. He could only believe that, although Sir Frederick had passed away, his life was not really ended, but was going on elsewhere under brighter and better conditions. The Council had that day passed the following resolution:—"This Council have received with great regret the intimation of the death of their esteemed colleague Sir Frederick Bramwell, Bart, F.R.S., Past-President. The Council desire to convey to Lady Bramwell and her daughters the expression of their sincere sympathy in this bereavement, and their high appreciation of the great services which Sir Frederick Bramwell has rendered to the Institution of Civil Engineers, and to engineering, during his long and distinguished professional career. He was elected an Associate in 1856, and transferred to full membership in 1862. Since 1867 he has served continuously on the Council, having been elected Vice-President in 1880, and President in December 1884, occupying the Chair until May 1886. The Institution owes much to his unwearied service, his wise counsel, unfailing generosity, and active work in connection with the initiation and foundation of the Benevolent Fund. His loss will be severely felt both in the business of the Council and at the ordinary meetings. No member of the Institution was a more faithful attendant at its meetings, or made more valuable contributions to the 'Proceedings.' With wide and varied experience were united gifts of expression and humour, as well as a ready appreciation of what was most valuable and promising in novel proposals. His colleagues desire to record their sense of his distinguished personal qualities, and will ever hold them in remembrance."

He now moved—

"That the members of the Institution of Civil Engineers, in ordinary meeting assembled, on behalf of themselves and their fellow-members, approve and endorse the resolution of the Council in regard to the death of Sir Frederick Bramwell, Past-President, and request it be entered on the Minutes."

The PRESIDENT then said: I should like to add one or two words of personal acknowledgment, and I am sure that in expressing my own feelings I shall express those of the members generally, in regard to the sad loss which the Institution has sustained by the death of our dear friend. Sir Frederick's long connection with the Institution and his faithful services it is impossible to exaggerate. How faithful he was in his loyalty to the Institution it is difficult to conceive. No private engagement was allowed to interfere with his Tuesday evenings, and everything he did in regard to his own occupation was always influenced by the consideration of whether he could be away from the Institution or not. He was an example to all in devotion and loyalty to the work of the Institution. It was nothing short of a life-long devotion; it did not tire as he grew older, and, session after session, he still occupied his familiar seat. You will no doubt all remember how only four weeks ago he stood at this table, and, in words which moved me deeply, proposed the vote of thanks for my Address. We little thought then that we should be lamenting his loss this evening. Another characteristic was his unwearied generosity, shown not only in giving sums of money, but by his interest in everything which made for the welfare of those who were connected with the Institution, his continued work for the Benevolent Fund, and his efforts to interest other people in that Fund. In every way—in many ways that need not be mentioned—he was unwearied in his efforts to help those who had any association with the Institution. He had a marvellous sympathy, especially with young men. He never seemed to grow old in his realization of what the feeling of the young must be, and he entered heartily into their hopes for the future. Although over 80, he was in his heart still young, ever interested in what was new, ever watchful, ever encouraging those who were pioneers, and, as far as I have heard, never once saying an unkind thing. He said many clever things and many true things, but he never said an unkind one. Looking back on all that, our loss is the greater. He united in himself both wisdom and wit, such as was given to few men. He had the art of terse expression, and, as has been well said of him, he could take an idea, clothe it in a new form, and give it back improved to the originator. When the Council had to deal with a particularly tangled piece of business they always turned instinctively to Sir Frederick Bramwell to put them right, and to put the idea on which they were agreed into language which admitted of no question. Those who have worked with him for years, remembering that when new difficulties shall crop up they

cannot look across the table to the seat that was never empty, and turn to the dear old face, always so bright and interested in what was being done, will feel keenly what a loss they have sustained. Sir Frederick loved work. I remember some years ago when a colleague who thought he had had enough of work was retiring, Sir Frederick said to him: "I will never retire, I shall work to the end. Life to me is work. I cannot conceive anyone finding at the end of a career of work, occupations of any other kind, and my interest is just as sustained as when I was a young man. I will work to the end." He did work to the end literally. Even when physical strength was failing, his heart never failed; he was ready and willing to work. After his fatal illness began, Sir Frederick, Dr. Kennedy, and I were among the electors for one of the professorships at Cambridge. I had conferred with Sir Frederick on the subject, and I knew he was seriously ill—but how ill I did not know; therefore I did not care to trouble him; but, to my intense surprise, from his sick chamber there came to me a letter showing that he still remembered that we were looking for his opinion, which was of the greatest service to us in our final selection—a letter written by a man who was then partly broken, but who never forgot the claims of duty, and who fulfilled them to the last. I should like also to say a word as to my personal indebtedness to Sir Frederick Bramwell. When I was ill, and worn and brain-tired, the man who cheered me and stood by me and comforted me was the man who now lies dead. One cannot forget a thing like that. I have said that Sir Frederick never gave up; no, he never gave up; only on Sunday last, when the shadows of death were gathering, he dictated the following message. His daughter, Lady Bliss, wrote to me on Monday, "My father dictated this to me last night; very anxious that it should be read at the Civils to-morrow. Will you kindly see that this is done. The doctor has just left and he says the end may come at any minute." This was the message: "Sir Frederick Bramwell dictated this message to be read at the Tuesday evening meeting of the Institution of Civil Engineers on December 1st: that he has looked forward to the opportunity of supporting his very dear friend Sir William White in the Chair as President during the Session. It is a source of bitter regret to him that that cannot now take place." Sir Frederick Bramwell was true to death; he never forgot the Institution; he never forgot his friends; and I therefore move that we record on the Minutes our recognition of and gratitude for such a life and such a death.

Sir JOHN WOLFE BARRY, K.C.B., Past-President, said:—I can add little to the eloquent words which have fallen from the President; they have touched my heart, as I am sure they have affected every one present. It is to me a melancholy satisfaction to be allowed to second the motion. Everyone who has had anything to do with the conduct of the business of the Institution will recognize how absolutely true it is that Sir Frederick Bramwell was essentially the father of the Institution, and that the Institution was as near to his heart as anything could be in this world. He was a man whose acts of kindness and benevolence, to both rich and poor, old and young, were not done in the light of day. Having enjoyed his friendship, I can bear testimony to the fact that such acts in his case were neither small nor few. When it is remembered what he did for science and technical education every one must be struck with the extraordinary fulness of Sir Frederick's life. He was a remarkably active member and supporter of the Royal Society, the Royal Institution, the British Association, the Society of Arts, the City and Guilds Institute, the Goldsmith's Institute and many professional societies, and all those institutions, I am sure, would say the same words that are being said here this evening, namely, that he has left behind him a blank which can never be filled. But of all the societies of which he was an ornament, there was none he loved so much as the Institution of Civil Engineers. It was part of his very life. He was always thinking about it and ever trying to do something for it. On such a melancholy occasion as this it is a great satisfaction to look back upon the great work of benevolence which he did for our members in the initiation of the Benevolent Fund. It was one of those things which gave him throughout his life since 1864 the most unadulterated satisfaction, in thinking that he had been instrumental (as in fact he was mainly instrumental) in founding that Fund, which has carried comfort and hope to so many homes in times of distress. To me personally the loss of Sir Frederick Bramwell is quite irreparable. The President has said that Sir Frederick was kind to the young. He was considerably my senior, and when I first started in independent practice in Westminster he was then almost as great an ornament to the profession as he was in after years. I look back upon the support and kindness which I received from Sir Frederick with the greatest gratitude. He seemed to have a peculiar pleasure in helping forward young men entering upon their profession and he was never weary of trying to guide them along the road which he had travelled. It is difficult to express my own feelings, but I am

sure my experience of Sir Frederick's kindness of heart and ready help is the experience of many members of our profession. Though the loss to me is irreparable, it is great satisfaction to be able to look back upon his life as a very happy one while it lasted, and it lasted many years. Those who loved him are glad to think that the end came, as he hoped, while he was in harness and while he was happy in his work and occupied with the things which he loved best. Years of decrepitude or invalidism would have been a sad ending to his busy life. Therefore in lamenting his loss it is some comfort to know that the end came as it did, and that we can look back upon our departed friend with lasting affection and with the knowledge that he did his work in life as few have ever been able to do theirs.

The resolution was agreed to in silence.

The PRESIDENT announced that by the great kindness of Canon Henson, and at the request of the Council, it had been arranged that a memorial service should be held at St. Margaret's Church, Westminster, at one o'clock on Friday, the day provisionally fixed for the funeral. Although the Institution had taken the lead in the arrangement of the service, the Council hoped to have the honour on that occasion of the presence of representatives of the many scientific and professional societies with which Sir Frederick Bramwell had been associated. The Institution had to thank Canon Henson for his prompt and courteous consent to the service taking place. It would be the business of the Secretary to announce the arrangements, but he mentioned the subject now in order that members of the Institution might make it known to other members who were not present that evening; so that there might be a suitable demonstration of the respect and honour in which Sir Frederick was held.[1]

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[1] The service in memory of Sir Frederick Bramwell was held on Friday, the 4th December, at St. Margaret's Church, Westminster. The Dean of Westminster officiated, assisted by the Rev. Canon Hensley Henson, Rector of St. Margaret's. Among the large congregation present were Lady Bliss, a daughter of the deceased, and Mr. H. Graham Harris, his partner. The Institution was represented by Sir William White, K.C.B., President, Sir George B. Bruce, Sir John Wolfe Barry, K.C.B., Sir Douglas Fox, Mr. Mansergh, Mr. Charles Hawksley, and Mr. J. C. Hawkshaw, Past-Presidents; Sir Guilford Molesworth, K.C.I.E., Sir Alexander Binnie, and Dr. Kennedy, Vice-Presidents, and almost the whole of the Council and staff, as well as by a large number of members. Among the numerous societies and other bodies represented—with many of which Sir Frederick Bramwell had been associated—were:—The Royal Society, the Ordnance Committee, the Royal Institution, the Royal Geographical Society, the Institution of Mechanical Engineers, the Institution of Naval

No member could feel that, after what had taken place, it would be possible to turn to other business that evening, and he therefore moved "That this meeting do now adjourn to December 8th." The resolution involved the postponement of the ballot which was to have taken place that evening, but he had no doubt the meeting would approve of the motion.

Sir JOHN WOLFE BARRY seconded the resolution, which was carried unanimously.

The meeting then adjourned.

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8 December, 1903.

Sir WILLIAM H. WHITE, K.C.B., D.Sc., LL.D., F.R.S., President, in the Chair.

The Council reported that they had recently admitted as

Students.

ALEXANDER ANDERSON.
ROBERT JOHN ANGUS.
CHARLES DUDLEY ARNOTT.
GEORGE NORMAN BAINES.
CHARLES JOHN BALDING.
FRANCIS WILLIAM BALSTON, B.A. (*Cantab.*)
WALTER GEORGE BANISTER.
LESLIE HOLDING BARNES.
LANCELOT EDWARD BECHER.
REGINALD BLABER.
GEORGE WILLIAM MAXIMILIAN BORNS.
CHARLES HENRY BRADLEY.
HAROLD SUGDEN BRAILSFORD.
FRANCIS WILLIAM MANFRED BURR.
ROBERT THOMAS ROWLEY PROBYN BUTLER.
ARCHIBALD CARMICHAEL.
THOMAS BIRCHALL CARTER.
ROBERT CHALMERS, B.Sc. (*St. Andrews.*)
WILLIAM ROY MILTON CHURCHER.
DAVID CLARK.
ERNEST CLARKE.
GEOFFREY CLARKE.
ARTHUR LUDLOW CLAYDEN.
HENRY COCKBURN.
HARRY STOWE COPPOCK, B.Sc. (*Wales.*
EDGAR MYRIE CORY.
HAROLD DOUGLAS CREEDY.
REGINALD HARRISON CRIPPS.

Architects, the Iron and Steel Institute, the Institution of Electrical Engineers, the Society of Arts, the Royal Institute of British Architects, the Surveyors' Institution, the Society of Engineers, the Incorporated Association of Municipal and County Engineers, the Junior Institution of Engineers, the Institution of Gas Engineers, the Royal Meteorological Society, the Society of Chemical Industry, the British Association of Waterworks Engineers, the Institution of Marine Engineers, the Institution of Mining Engineers, the Institution of Mining and Metallurgy, the Goldsmiths' Company, the Goldsmiths' Institute, the City and Guilds Technical Institute, and others. The interment took place at Hever, Kent, the country residence of the deceased.

Students—continued.

David Tudor Davies.
Theophilus Maxwell Davies, B.A. (*Cantab.*)
Edgar De Lautour.
Ernest Dobson.
John Dobie Halliday Dymock.
Arthur Dyson.
Hubert Dyson.
Stanley Steuart Elliott, B.A. (*Cape.*)
Basil Prockter Fletcher.
Charles Godfrey Forbes.
Peter Logan Raeburn Fraser.
Thomas George Garforth.
Harold Burton Gates.
Maelgwyn Glendower George, B.Sc. (*Wales.*)
Charles William Gibbs.
Martin Gimson.
Alan Trevanion Grant-Dalton.
Robert George Hannington.
Arnold William Elsmere Harris.
Norman Edmond Harrison.
Sidney Hartley.
Lawrence Hector Mark Heathcote.
Frederick George Helsby.
William Henry.
Horace John Elliott Hone.
Thomas MacMillan Hunter, M.A., B.Sc. (*Glasgow*).
James Annacker Hutchinson.
Robert John Mathison Inglis.
Lionel Herbert Jacob.
Gwilym Aneurin Jones.
José Petronio Katigbak.
Claud George Kent.
Thomas James Kirkland.
Walter Dingle Knight.
Ernest William Lace.
Onward Bayes Lacey.
Leslie Carlton Lambert.
Ernest Latham, Junr.
Alfred Jean Alexis Leclezio.
William Phillip Lewis.
Edwin Guy Lidstone Lovegrove.
Conrad Offa Lowsley.
Norman Nathan Maas.
David Bird McLay.
Alastair Marcell Macnab.
Apparandra Bopanna Madapa.
Francis Joseph William Maddox.
Robert Malthus, B.A. (*Cantab.*)
Frederick Percy Manson.
Harold Marsland.
Frank Henry Matthew.
Leopold George Edmond Morse.
Harold Sutcliffe Mort, B.Sc. (*Sydney.*)
Harold Alexander Newton.
John Hedley Nicholson.
Edward Stafford Northcote.
Edward Oakden.
Alf Oldfield.
Guy Clevland Onslow.
Geoffrey Parker.
Eustice Rayne Parmiter.
Thomas Sylvanus Pipe.
Armell Richard Pollard, B.A. (*Cantab.*)
Alfred Bertrand Potts.
Pier Alessandro Georgio Rappis, B.A. (*Cantab.*)
Douglas Walter Julius Ravenhill.
Bertie Reynolds.
Leopold Penrose Ridgway.
Herbert Priestley Robarts.
Reginald Braham Robinson.
Harold George Rowley.
Alfred Ernest Ruffhead.
William Joseph Rusdell.
Frank James Salberg.
Charles Vaughan Sandeman.
Charles Arthur Sharpe, B.A. (*Cantab.*)
Francis Blewett Shaw.
Thomas Alfred Shaw.
Charles Westcar Sheppard.
Frederick Walter Skelsey.
George Makins Smith.
John Woodhead Smith.
Herbert Speight.
Maximilian Harold Spencer.
Alexander Cecil Stern.
Donald MacIver Stewart.
William Stead Strachan.
Herbert Charles Swayne.
Oliver Henry Teulon.

Students—continued.

MARTIN LEWIS THOMAS.
WILLIAM CLAUDE THOMAS.
BERNARD VALENTINE THOMPSON.
FRANK TIFFANY, Junr.
WALTER ALEXANDER TURNBULL.
STANLEY MARTIN UDALE.
ROBERT URE.
JAMES ARTHUR UTTLEY, B.Sc. (*Victoria.*)
ROGER FERDINAND VOGEL.
HORACE FRANK WATERS.
HERBERT WATSON, B.E. (*Royal.*)
LEONARD ALEC VERNON WEBB.
WILLIAM WELLS.
HAROLD JOSEPH WHEATON.
AUGUSTUS WHILE.
ROBERT WILLIAM WILL, Junr.
MARTIN WOLFF.
ALBERT FREDERICK JAMES WRIGHT.
HAROLD EDGAR YARROW.

The discussion on Dr. Mill's Paper, "On the Distribution of Mean and Extreme Annual Rainfall over the British Isles," occupied the evening.

Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 3339.*)

"Recent Road-Bridge Practice in New South Wales."

By Henry Harvey Dare, M.E., Assoc. M. Inst. C.E.

Exclusive of railway-bridges, road-bridges over railway-lines, and culverts of less than 25 feet span, there are about three thousand road-bridges, having an aggregate length of about 54 miles, in the State of New South Wales. The design, construction, and maintenance of the whole of these structures are under the control of the Roads and Bridges Branch of the Public Works Department, with the exception of a few bridges within municipalities, the latter being responsible for the upkeep and renewal of the decks of existing road-bridges, but usually not having sufficient funds for the erection of new bridges, except those of a minor character.

At the present time the quantity of iron and steel plates and rolled sections manufactured in the State is very small, and, owing to the distance from the markets of Europe and America, the use of imported material involves considerable delay and expense; consequently, bridges constructed of iron and steel are not employed, except in special cases, full advantage being taken for ordinary purposes of the magnificent hardwoods, of which New South Wales fortunately possesses a number of varieties.

Timbers of New South Wales suitable for Bridge-building.—The hardwood timbers of New South Wales are second to none in Australia, and indeed compare favourably, both for strength and durability, with any timbers in the world. The principal timber-growing areas are in the coastal districts to the north and south of Sydney, chiefly the former, where the hardwoods are abundantly distributed and attain a great size. Inland, with the exception of a few districts, timber is scarce, and it is customary in the case of most of the bridges erected in the central and western divisions of the State to take the timber from the coast, often at great expense for carriage by road and rail. Until comparatively recent years, but little was known of the strength of Australian timbers. The results of some tests on small specimens of a few varieties are

incorporated in Laslett's "Timber and Timber Trees," published in 1875, and isolated tests were also made subsequently by other authorities; but it was not until 1886 that the matter was systematically investigated by Professor W. H. Warren, M. Inst. C.E., Professor of Engineering at the University of Sydney. In all, some 1,500 tests were made in the engineering laboratory of the University. The results are embodied in Professor Warren's work on "Australian Timbers," published in 1893, from which the following Table, given with Professor Warren's permission, has been prepared by the Author,[1] who assisted at many of the tests.

The dimensions of the specimens upon which the tests recorded in the Table were made, were:—for transverse-tests, 6 inches by 4 inches, by 48 inches between supports; for compression-tests, about 3 inches by 3 inches; for tension-tests, 1 inch and ½ inch in diameter; and for shearing-tests, 6 inches by 6 inches, by 2 inches along the grain. Comparing the tabulated values for the modulus of rupture with those obtained from a few tests of large flitches and girders of ironbark up to 12½ inches square, on supports 28 feet 6 inches apart, it would appear that a reduction of about 25 per cent. is necessary in fixing the modulus of rupture for large girders. The Author's practice, in designing timber structures, is to adopt a value of 13,440 lbs., or 6 tons, per square inch, for the modulus of rupture of ironbark, and 11,200 lbs., or 5 tons, per square inch, for most of the other hardwoods mentioned in the Table.

The quality of the timber varies considerably, depending on the district in which it is grown, and some of the varieties named are not much used for girders or other members where the transverse strength is an important consideration, but are quite suitable for decking and for minor portions of the structures. For trusses, ironbark is invariably used.

With regard to the use of timber in salt water, turpentine-piles are sometimes employed with the bark on, but where the teredo and limnoria are active no class of timber can be considered safe against their attacks, and Monier armour is now used to protect the piles in such cases.

As illustrating the durability of New South Wales timbers, the Author has compiled the following particulars of the life of one

[1] Professor W. C. Kernot, of Melbourne University, has also made a number of tests, principally on Victorian timbers. These are recorded in a work by Mr. James Mann on "Australian Timber," 1900.

New South Wales Timbers used in Bridge Work.

Summary of Results of Experiments made by Prof. W. H. Warren, Sydney University.

Name of Timber.	Weight in Lbs. per Cubic Foot.	Modulus of Rupture.	Modulus of Elasticity from Transverse Tests.	Compressive Strength in Lbs. per Square Inch. Ratio of Length to Least Dimension.					Modulus of Elasticity from Compression Tests.	Tensile Strength in Lbs. per Square Inch.	Shearing Strength in Lbs. per Square Inch.
				4 to 1.	8 to 1.	16 to 1.	24 to 1.	36 to 1.			
		Lbs. per Square Inch.	Lbs. per Square Inch.						Lbs. per Square Inch.		
Ironbark . . .	73	18,205	2,635,470	10,572	9,764	9,670	7,875	6,866	1,951,010	21,700*	2,164
Grey Gum . . .	70	17,581	2,547,300	9,822	10,178	8,134	7,357	5,125	1,873,713	17,709	2,041
Grey Box . . .	73	16,209	2,766,435	8,021	8,525	8,032	7,210	Not given	2,048,940	21,897	2,095
Brush Box . . .	63	15,821	2,052,770	8,827	7,914	7,223	5,722	4,343	1,703,181	13,236	2,140
Messmate . . .	54	15,414	2,137,383	9,037	9,517	7,786	7,233	5,264	1,849,824	16,081	1,688
Forest Mahogany .	69	15,290	2,607,908	8,477	8,095	7,986	6,786	5,641	1,693,139	20,353	1,719
Tallow-wood . .	71	15,272	2,248,613	8,548	7,987	7,767	5,942	5,169	1,750,223	14,744	1,667
Spotted Gum . .	60	15,245	2,351,002	8,545	7,921	7,966	6,207	5,250	1,961,717	16,440	2,005
Blackbutt . . .	62	14,845	2,167,880	8,611	8,170	7,762	6,309	6,008	1,808,034	21,112	1,821
Blue Gum . . .	67	14,765	2,160,509	8,090	8,049	7,977	6,842	6,259	1,736,825	17,452	1,880
Red Gum (*E. Tereticornis*) .	70	14,608	2,101,005	9,397	7,915	7,265	5,208	5,000	1,668,634	13,618	2,039
Turpentine . . .	65	14,381	1,976,530	8,495	7,906	7,288	5,514	4,781	1,605,758	17,854	1,636
Woollybutt . . .	64	14,182	2,255,640	7,168	7,784	6,884	5,931	4,975	1,589,023	19,190	1,728
Mountain Gum . .	60	13,260	1,615,520	7,258	7,850	6,785	7,056	3,656	1,607,850	13,494	1,870
Stringy Bark . .	61	13,083	1,884,042	6,698	7,636	6,805	5,920	3,651	1,505,579	15,976	2,089
Mountain Ash . .	54	12,148	1,965,665	7,403	7,693	6,419	5,665	5,656	1,580,416	19,713	2,102
Murray Red Gum (*E. Rostrata*) . .	64	9,098	1,067,650	6,298	4,920	6,030	3,775	3,325	1,023,077	8,571	1,818

* Red and grey ironbark.

hundred and thirty timber bridges within the State, which have been renewed during the past six years.

	Truss-Bridges. Number, per Cent.		Beam-Bridges. Number, per Cent.	
Life not exceeding 20 years . .	7 =	19·0	24 =	25·0
„ 20 to 25 years	13 =	36·0	31 =	33·0
„ 25 to 30 years	6 =	17·0	11 =	12·0
„ exceeding 30 years . . .	10 =	28·0	28 =	30·0
	Total 36	100·0	Total 94	100·0

These figures speak for themselves, and with the improved systems of construction now in vogue, and the rigid inspection of the timber used in all bridges at the present time, it is only reasonable to expect that the life of timber bridges in the future will be even longer than it has been in the past.

Present Practice in New South Wales.—Where the conditions are such as to permit of their erection, timber-beam bridges are employed, but in many instances, owing to the height of the flood, or to the quantity of débris carried by the stream when in flood, a longer span is required than can be provided in the simple beam type. In such cases truss-spans of the composite type are now generally adopted, up to the limit of span at which it becomes more economical to employ steel truss-bridges. Suspension-bridges are occasionally erected, but circumstances are not usually favourable to the economical use of this type of structure, nor to that of the cantilever, or metal-arch. Masonry-arches are but little used, since in the first place there are comparatively few sites where the highest floods do not either reach to, or overtop, the banks of the stream to be crossed, thus prohibiting the adoption of the arch type of structure; and in the second place they cannot compare in economy with timber or composite structures, where timber of such excellent quality is to be obtained. They are occasionally employed, however, generally in small spans, over gullies, on roads subjected to fairly heavy traffic. Considerable attention has lately been directed to the use of ferro-concrete iron arches, and two arch-bridges of this type, on the Monier principle, have been recently erected, with successful results, whilst a low-level ferro-concrete iron arch-bridge, consisting of thirteen spans, each 50 feet in the clear, is now in course of construction. The bridges described in this Paper have been selected as types of a number of bridges designed by the Author, which have been erected during the years 1899–1903.

Beam Bridges.—These are of two classes, viz.: those in which the deck is kept above the highest known flood-level (usually 2 feet

6 inches above that level), and those which are below flood-level, sometimes as much as 50 feet, the deck-level being 6 feet to 10 feet above the ordinary summer water-level of the creek or river to be crossed. The former are usually constructed with a roadway 15 feet in width between the curbs where the traffic is not large; but in or near country towns this is increased to 20 feet between the curbs, a 5-foot footway frequently being added, whilst in sparsely-populated districts the roadway is sometimes reduced to 10 feet in width between the curbs. These bridges are built in spans of 25 feet, 30 feet, and 35 feet, as simple timber beams, with corbels over the piers in the case of the 30-foot and 35-foot spans. Where the span exceeds 35 feet, compound timber beams are employed in spans of 40 feet and 45 feet, and in exceptional cases up to 50 feet span; above this limit truss-bridges are adopted.

In Figs 2 and 3, Plate 4, are shown some of the standard details for a high-level timber-beam bridge of 15 feet width of roadway. The outer girders are hewn and the inner girders are round, flatted on the top for the planking, and on the underside where they bear on the corbels or capwales over the piers and abutments. To exclude round girders having an objectionable taper, it is customary to specify, in addition to the centre measurement, a minimum circumference at the smaller end, as well as a minimum distance between the flatted surfaces at that end. Piers are formed of three or more piles, 12 inches in diameter at the smaller end, stiffened with braces and walings, 10 inches by 5 inches, and connected at the top with double capwales, 12 inches by 6 inches, sawn or hewn, free of heart.

Since many of the bridges erected are in soft alluvial ground, where it is often difficult to obtain the specified tests with sharp-pointed piles, a blunt point is sometimes used, Figs. 3, Plate 4; and in very soft ground timber-cleats are bolted to the pile. Pile-shoes are only found necessary where the driving is very stiff, or where coarse gravel or boulders are encountered. Piles are usually driven about 20 feet, but when the bed-rock occurs close to the surface they are either potted into it to a depth of 3 feet, after removing the sap-timber, or are connected to sills on a base of concrete, Figs. 3, Plate 4. Lewis-wedges are only used where the current is very strong, and a concrete base cannot be economically employed. Concrete- and masonry-piers are also frequently erected where the height is not great, and the foundation shallow. Low-level bridges are of the same general type as the high-level bridges, but have an additional pile in the piers, except where

large quantities of drift-timber have to be provided against, when piers having six piles are employed, Fig. 4, Plate 4. The hand-rails of low-level bridges are of light construction, so as to yield to the pressure of drift-timber, and to break off before the stability of the structure is endangered.

Camden Bridge.—The largest low-level bridge in the State is that recently completed over the Nepean River at Camden, Fig. 1, Plate 4. This structure has been built to replace an old timber bridge, and consists of five plate-girder spans, each 45 feet centre to centre of bearings, on concrete piers about 35 feet in height, founded on piles at a depth of about 5 feet below the bed of the river, with 165 feet length of timber approach-spans. In each span there are four steel plate-girders, 3 feet 6 inches in depth, braced together and carrying a roadway 20 feet in width on their top flanges, Fig 5, Plate 4. The bracing between the girders serves the double purpose of carrying the intermediate timber stringers supporting the deck-planking, and of stiffening the structure against flood-water and floating débris. In addition to the roadway-girders there are two independent plate-girders of stiffer section, upon the same piers, on the downstream side, which carry a light railway operated by tank-engines weighing 56 tons, with 14½ tons on the driving-axle. The deck of the bridge is 17 feet below the highest flood-level, and in a wet season the bridge is liable to be frequently submerged. For this reason iron hand-rails have been provided, the standards of which have cast-iron counterweights on their lower ends, and are pivoted at the level of the curbs. In flood-time the whole of the hand-rails on either side of each span are folded down in one piece behind the curbs. This bridge was erected by day-labour at a cost of about £10,000. No less than seven floods passed over the bridge during its construction, giving rise to some difficulty with the foundations of the concrete piers, which were put in with cofferdams formed of 4-inch sheet-piling, with metal tongues. It was finally found necessary to complete the lower courses of the concrete in the wet, using loosely-woven bags to contain the concrete. The main girders were brought to the site riveted up complete, and no staging was required.

Composite Truss Bridges.—The standard timber-truss employed for many years was one having timber chords and braces, and vertical suspension-rods. In the bridges of this type designed by Mr. Percy Allan, M. Inst. C.E., between 1893 and 1899, many improvements were introduced, and these bridges will doubtless prove more durable and less costly to maintain than their prede-

cessors. It has been found, however, that in almost every case the timber lower-chord has been the first member of the truss to fail, and the flitches, being in tension, are very difficult to replace. Since, moreover, during the past few years an extensive export trade in New South Wales timber has developed, lower-chord timbers, which must be of the best quality of ironbark, are becoming more expensive and more difficult to obtain than was the case previously. For these reasons it was decided some five years ago to adopt, as the standard, a type of truss in which timber is used only in the compression-members, whilst the tension-members are constructed of wrought iron and steel. A number of bridges of this class, designed by the Author, have been erected during the past five years, having composite truss-spans of 70 feet, 91 feet, 104 feet, and 117 feet, all of the Pratt type, with timber upper-chords and verticals, steel lower-chords, and wrought-iron diagonals.

Wyong Bridge.—This bridge consists of one composite truss-span of 91 feet, two 50-foot compound beam-spans, and two 35-foot beam-spans, the roadway being 15 feet in width between the curbs, Fig. 6, Plate 4. Each of the two cylinder-piers consists of a pair of Monier cylinders,[1] 4 feet in internal diameter, connected with steel bracing as shown in Fig. 7, Plate 4. Some difficulty was anticipated by the contractors in using air-pressure with this type of cylinder, and experiments were accordingly made by Mr. W. Baltzer, Engineer to the manufacturers of the cylinders, Messrs. Gummow, Forrest and Company, in order to ascertain the best class of materials for making the joints between the cylinders. This appeared from the experiments to be a mixture of 1 lb. of bitumen to $1\frac{3}{4}$ oz. of fish-oil, with sufficient cork-dust added to give the heated mixture the proper consistency. In sinking the cylinders at Wyong Bridge, this mixture was smeared hot over the top surface of each length of cylinder, and the two lengths to be jointed were drawn tightly together with steel pilot-wedges; the small connecting-wedges were then inserted, and the inner surface of the cylinders at the joints was coated with bitumen, and smoothed off with a hot iron. Some leakage of the compressed air was found to take place through the holes in which the wedges were driven; but this was obviated by the simple expedient of stretching a piece of American cloth round the joint. In other cylinders of the same type, sunk under a moderate air-pressure,

[1] *Vide* "Monier pipes as a pile covering, and in place of cast iron for cylinder foundations," by E. M. de Burgh, M. Inst. C.E. Minutes of Proceedings Inst. C.E., vol. cxlii. p. 288.

the above-mentioned mixture was used for the joints, and the wedge-holes were filled with soft-wood strips smeared with bitumen, and no leakage occurred; in other cases an ordinary red-lead joint has been successfully employed, but in no case have Monier cylinders yet been sunk with air-pressures exceeding 20 lbs. per square inch.

The lower chords in Wyong Bridge are of the standard type adopted in this form of truss, viz., two steel plates 12 inches in depth, spaced 12 inches apart, laced together in the end bays, and connected at each apex with diaphragms and saddle-plates carrying the timber cross-girders. The vertical struts are of timber, each formed of two sawn pieces seated on the saddle-plates, and securely connected to the lower chords by extending the angle-bars of one of the diaphragms upwards, and bolting right through the verticals and cross-girder. The top chords consist of two sawn timbers free of heart, with a space of 4 inches between. They are connected at each apex by a casting recessed 1¼ inch into the inner side of each flitch, for the full depth, and bolted through. The notching takes the horizontal component of the stress in the diagonal-rods, and the castings, acting as rigid distance-pieces connected to the vertical struts, prevent any tendency to twist on the part of the timber flitches, and ensure that the chords shall keep a good line.

Wind-bracing, consisting of diagonal-rods with turn-buckles, is provided between the lower chords, and the top chords are stiffened against vibration by side stiffeners of T-section, connecting the chord with the cross-girders, which are extended outwards for that purpose. The diagonal-rods are of wrought iron, screwed at the upper end, and having an eye forged on the lower end, which is connected to the lower chord by a pin at each apex. The ends of the chords are seated on cast-iron bed-plates, a gun-metal or rolled-brass plate, ½ inch in thickness, being interposed loosely between the wrought-iron bearing-plate on the under side of the chord and the bed-plate at the expansion-end of each span.

The timber piers of Wyong Bridge have been protected against the teredo by means of Monier pile-armour, 21 inches in diameter. This armour has been largely and very successfully used in a number of bridges erected during the past five years. In some of the more recent bridges, square piles, 12 inches by 12 inches, have been used instead of round piles, and the diameter of the pile-armour has been reduced to 18 inches, the guide-battens for the Monier pipes being dispensed with.

The total cost of Wyong Bridge and approaches was £3,850. This is considerably more than it would have cost some few years

ago, the price of all building-materials in the State being very high at the present time.

Tabulam Bridge.—The Clarence River, over which this bridge has been erected, is one of the coastal rivers of New South Wales, flowing through heavily-timbered country, and subject to high floods in a wet season.

The bridge consists of five composite truss-spans, each 104 feet centre to centre of bearings, and 13 feet in depth, with 445 feet length of timber approach-spans (Fig. 8, Plate 4); the general design of truss employed is similar to that described for the Wyong Bridge. The main piers are built of concrete, and are 63 feet in height and 7 feet in thickness at the base, Fig. 9, Plate 4. They were constructed in open coffer-dams, consisting of single sheeting, which were pumped dry before the concrete was laid. Rubble concrete has been used for the bodies of the piers, and fine concrete for the upper portions, and the surface has been rendered, $\frac{5}{8}$ inch in thickness, where exposed to view. Each of the timber piers carrying the shore ends of the truss-spans consists of nine vertical piles, hewn 12 inches by 12 inches, and three stump-piles, the whole braced with hewn compression-struts, and sawn braces and walings.

This bridge has been carried out by day-labour under Mr. D. W. Armstrong, Assoc. M. Inst. C.E., Resident Engineer, at a cost of about £13,000, including extensive approaches. It was opened for traffic at the beginning of 1903.

St. Albans Bridge.—In the truss-bridge recently erected over the MacDonald River at St. Albans, about 50 miles north of Sydney, there are two composite Pratt truss-spans, each 117 feet centre to centre of bearings, carried on cylinder-piers at a height of 52 feet above the river-bed. The arrangement of the details of the truss members is somewhat different from that already described, in order to provide for the additional sectional areas required, due to the longer span, but the difference is not sufficient to warrant a detailed description in this case.

Lane Cove Bridge.—This bridge (Fig. 10, Plate 4) was completed by day-labour at the beginning of 1901 at a cost of £3,800, including extensive approaches. The main span is 165 feet, centre to centre of bearings, and consists of a composite under-truss, 22 feet 6 inches in depth. This is the longest composite span yet erected in the State.[1] The bridge, which is distant about

[1] The Cowra Bridge, designed by Mr. J. A. MacDonald, M. Inst. C.E., in 1891, has three bowstring composite truss-spans, each 160 feet centre to centre of bearings.

12 miles from Sydney, spans a gorge where the flood-level is of no great height, thus admitting of the adoption of a span having the deck on top of the trusses. It was at first intended to erect an economical type of suspension-bridge at this site, but the under-truss adopted was found on investigation to be less costly.

The main trusses of this bridge are spaced 15 feet apart, centre to centre, and consist each of a top chord formed of two hewn ironbark timbers, 13 inches by 12 inches, with timber verticals, and a steel lower-chord built of a pair of steel plates 15 inches in depth, varying in thickness between $\frac{1}{2}$ inch in the end bays and $\frac{7}{8}$ inch at the centre of the span. At each lower apex there is a saddle to carry the vertical strut, and gussets, both for the horizontal wind-bracing between the chords, and for the vertical sway-bracing between the trusses. The end bays of the lower chord, which are not subject to any direct tension, are stiffened by means of angle-bars riveted to the chord-plates and connected by lacing at the top and bottom. The diagonal-rods are of wrought iron, bearing on bevelled forgings let into the timber chords at the top. For the connection of the lower ends of the rods to the steel chords it was found that the size of the pins required would have been excessive if the type of detail used in smaller trusses had been adopted; a different form of connection was therefore used, Figs. 11, Plate 4. This consists of a forged rectangular trunnion-block at each lower apex, with pin ends, set at the correct angle to receive the rods, and built into the chord during manufacture. These trunnion-blocks vary between $6\frac{1}{2}$ inches by 6 inches for the end rods and $4\frac{1}{2}$ inches by $4\frac{1}{2}$ inches for those at the centre, and have holes drilled and tapped to receive the ends of the rods, which, when in position, are secured through the trunnion-block, each by a steel tapered pin.

The expansion-bearings, devised for this work, are formed each of an upper saddle bolted to the underside of the steel chord and a lower saddle secured to the bed-rock. Between these there is a solid cast-iron rocking-link working on wrought-iron pins, top and bottom,—the pins being provided with collars to prevent side movement, Figs. 12, Plate 4. These bearings have proved satisfactory. At the fixed bearings the rocking-links are omitted.

The two timber approach-spans at either end were erected first, and served as platforms in connection with the subsequent operations. The lower chords of the trusses were built on staging and the trusses were erected over them, the members being handled

from an overhead wire-rope stretched over a temporary trestle on either bank, and carrying a traveller from which depended a wire-rope with a snatch-block operated from a winch on the approach-spans. The deck, which is 18 feet in width between the curbs, is carried on ironbark cross-girders resting on the upper chords. The planking is laid diagonally to ensure stiffness; and no horizontal system of wind-bracing is required between the upper chords.

In the United States, where composite bridges were at one time extensively employed, they have now been practically superseded, owing to the enormous increase in the output of steel during recent years. In New South Wales, however, the conditions are altogether different, since, as has already been stated, the supply of steel is very limited in the State, while the timbers are greatly superior to those of the United States, both in strength and durability. For these reasons the composite truss represents an economical and durable type of structure, erected without difficulty, and easily renewed, since the lower chord is of a permanent nature, and the timber members, which require renewal at intervals of about 30 years, are all in compression, and can be easily replaced. The lengths of the spans adopted have been found from extensive experience to be well adapted to the character of the streams which have to be bridged. No trouble owing to the unequal expansion of the timber and steel members has been experienced with any of the composite truss-bridges yet erected.

Luskintyre Bridge.—Like most of the coastal rivers in the State, the Hunter River is subject to very high floods, which rise rapidly and carry considerable quantities of drift-timber. At Luskintyre, the River at ordinary summer-level is only a small stream some few inches in depth, but in high floods it rises to about 69 feet above the bed, and flows with a strong current. The main bridge (Fig. 13, Plate 4), which was completed at the end of 1903 at a cost of about £18,000, consists of two steel riveted truss-spans, each 198 feet centre to centre of bearings and 25 feet centre to centre of chords, carrying a timber deck 18 feet in width, on steel cross-girders spaced 18 feet apart. The bridge is designed to carry a live-load of 84 pounds per square foot, or a traction-engine weighing 16 tons.

The method of determining the sectional areas required in bridge members now adopted in the Branch of the Public Works Department to which the Author is attached, is to adopt a fixed working-stress for all members, and to increase the live-load stresses

in a certain ratio in order to make allowance for the effect of dynamic action. Although a road-bridge is subjected to far less shock and vibration from live-load than a railway-bridge, it is reasonable to suppose that inequalities in a timber-plank deck due to unequal wear of the planking, or in a metalled deck due to loose road-metal and unequal wear of the surface, must, to some extent, increase the stresses induced by a heavy load rolling over the bridge, especially those in the stringers and cross-girders, which are the members most affected by a heavy concentrated load such as a traction-engine. Most country bridges, too, have frequently to carry considerable mobs of travelling stock, which may cross the structure at a trotting-pace, and set up vibration, and this in the main trusses of a long span may be cumulative, increasing the deflection beyond that due to a static load. So far as the Author is aware there have been no experiments to determine the effect of moving live-loads on road-bridges; but it appears to be recognized by leading authorities on bridge design that some allowance should be made where moving loads have to be provided for. For example, in the well-known Specifications for Highway-Bridges of Theodore Cooper, the working-stress for truss members is fixed at 22,000 lbs. per square inch for dead-loads, whilst for live-loads it is only 11,000 lbs. per square inch. The most rational method of allowing for the increased effect of live-loads appears to be that recently formulated by Mr. J. H. Schaub, of the United States, which he states was first proposed by Mr. H. S. Prichard in 1895, viz., to add to the live-load a percentage determined by the ratio of the live-load to the total load on the structure. This method takes into account the effect of the inertia of the structure in resisting shock and vibration, and has been adopted by the Author in his recent practice, using certain empirical constants, which, in the absence of experimental data on road-bridges, he has deduced from the results of experiments made by various investigators—notably Mr. Turneaure, of the United States—on railway-bridge structures. These constants must be considered as arbitrary only, but they have been found to give satisfactory results.

The application of the principle lies in first determining the bending-moments, or the direct tensile or compressive stresses, due to dead and live load, for each member of the structure, and then adding to the live-load bending-moment, or live-load direct stress, an amount

$$I = C \times \left(L \times \frac{L}{L + D}\right)$$

Where D is the bending-moment or stress due to the dead-load.

L is the bending-moment or stress due to the live-load.

I is the amount to be added to the live-load bending-moment, or live-load stress, to cover dynamic action.

C is a constant having the values 0·75 for a train-load on a railway-bridge, 0·30 for a traction-engine or other rolling load on a road-bridge, and 0·15 for a live-load, which in New South Wales is taken as 84 lbs. per square foot on an ordinary road-bridge, or 100 lbs. per square foot in a city bridge.

The sum of D, L, and I, gives the total stress in the member, and the sectional area required is then determined by using a fixed working-stress.

The following summary of the stresses and cross-sectional areas for the stringers, cross-girders, and main trusses of Luskintyre Bridge will show how the method is applied. The specification for the structure requires that the whole of the work shall be of steel, having an ultimate strength of 26 tons to 31 tons per square inch, with an ultimate elongation of not less than 20 per cent. measured on a length of 10 inches under test, and a contraction of area of not less than 40 per cent.

The working-stresses adopted were :—

	Lbs. per Square Inch.
Tension—	
Dead and live load (plus impact)	$P = 17{,}000$
Wind-pressure	$P = 20{,}000$
Compression—	
Dead and live load (plus impact)	$P = 17{,}000 - 80\,\frac{l}{r}$.
Wind-pressure	$P = 20{,}000 - 100\,\frac{l}{r}$.

The wind-pressure allowed for is 50 lbs. per square foot, but this is not considered as acting when the structure is subjected to the full live-load.

The following are the estimated stresses, and values of I, for some members in Luskintyre Bridge :—

	Inch-Tons.
Stringers—	
Maximum bending-moment due to dead-load . .	D = 36
„ „ „ „ traction-engine	L = 211
Addition for impact $I = 0{\cdot}30 \times 0{\cdot}86 \times 211$ . .	= 55
	Total 302
Cross-girders—	
Maximum bending-moment due to dead-load . .	D = 299
„ „ „ „ traction-engine	L = 607
Addition for impact $I = 0{\cdot}30 \times 0{\cdot}67 \times 607$.	= 122
	Total 1,028

Trusses.—In the following Table are shown the stresses in different members of the trusses.

Member.	Dead-Load Stress. D.	Live-Load Stress. L.	Addition for Impact. $I = C \times L \times \frac{L}{L \times D}$.	Total Stress.	Working Stress.	Sectional Area Required.
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs. per Sq. Inch.	Sq. Inches.
Upper chord, end bay .	163,100	137,100	9,600	+309,800	17,000 − (80 × 37) = 14,000	+22·1
Lower chord, centre bay .	272,300	228,600	16,000	−516,900	17,000	−30·9
Vertical in second bay .	75,600	69,300	4,900	+149,800	17,000 − (80 × 70) = 11,400	+13·1
End diagonal.	124,200	106,700	8,000	−238,900	17,000	−14·1

It will be seen that in the case of the deck-system, where D is small compared with L, and L is due to rolling-load, I = 12 to 18 per cent. of the total stress; whilst for the trusses, where D and L are nearly equal, and L is due to a load of 84 lbs. per square foot, I constitutes only a small fraction of the total stress. This is equivalent to stating that the inertia of the trusses is much greater than that of the deck-system, and that in consequence the effect of impact is much less in the former than in the latter.

Typical chord-sections for the end bays are shown in Figs. 14, Plate 4. The additional section required in the bays of the chords nearer the centre is obtained by the addition of side reinforcing-plates, thus concentrating the area about the centre of gravity of the chords as much as possible. The trusses are connected at each upper panel-point by a lateral strut, and rigid portal-bracing is provided at either end. Upper and lower systems of wind-bracing are also provided, all the members having riveted connections. The floor-system consists of steel cross-girders seated on gusset-plates on the lower chords, and riveted to the vertical posts, the two channel-bars of which are connected at this point by a rigid diaphragm to ensure equal distribution of the load on both members of the lower chords. The stringers are of ironbark carrying a timber deck 4 inches in thickness and 18 feet in width. The trusses have also been designed to permit of the addition of a 5-foot footway, if required. Owing to the great height of the pier, the wrought-iron cylinders have been placed on a batter of 1 in 12 in order to obtain a wide base. They are connected above ground-level to cast-iron cylinders, sunk to the bed-rock, and all the cylinders are filled with concrete.

Opening-Bridges.—There are two classes of navigable waters in New South Wales, viz.: (1) the coastal rivers and creeks, which are available for masted vessels, and (2) the western river-system, embracing the great rivers Darling, Murray, and Murrumbidgee, where river-steamers and barges constitute the only traffic. In the case of the latter the steamers are of the paddle-wheel or stern-wheel type, the top of the funnel or of the "tow-post" being the highest point for which clearance has to be provided. This, in extreme cases, is as much as 36 feet above water-level, and the maximum width over the paddles is about 39 feet. A number of bridges of the lifting-type have been erected over these inland rivers. With some modifications of detail these are all of the type introduced by Mr. J. A. MacDonald, M. Inst. C.E., when Engineer for Bridges, and consist of a steel lifting-span, counterbalanced at each corner, and giving a clear opening of about 52 feet between the cylinders, horizontally, and 40 feet above summer water-level vertically, when the span is raised to its full height.

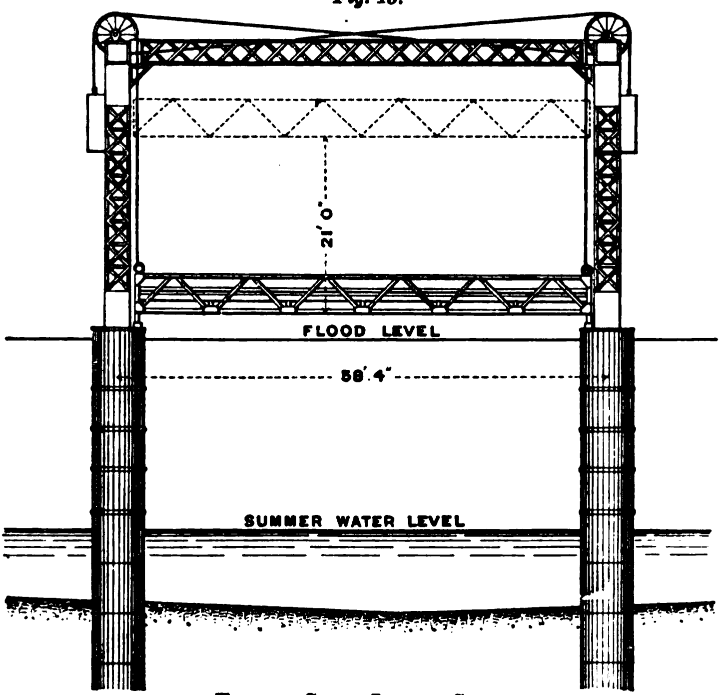
A bridge of this type, *Fig. 15*, costing about £14,500 was erected in 1902 over the Murray River at Cobram, under Mr. J. B. A. Reed, Resident Engineer. The girders of the lifting-span are of steel, of the Warren type, and carry a timber deck, 14 feet in width between the curbs. The towers are constructed each of four angle-bars braced together and connected at the top by lattice-girders in both the longitudinal and the transverse direction. The weight of the lifting-span is about 34 tons, and this is counter-balanced by four cast-iron balance-boxes, built in segments and filled with lead, the lead in the top sections of the balance-boxes being in ingots, to allow of adjustment when the timber deck of the span seasons and loses weight. The span is operated from the deck-level by means of gearing fixed at the top of one of the towers, and operating one of the rope-wheels. This rope-wheel is connected, by means of a transverse shaft, with that on the other tower upon the same pier, and motion is transmitted to the two rope-wheels upon the opposite towers by an arrangement of the ropes, whereby each rope passes from the top of the balance-weight at one tower, over one rope-wheel, and under and round that on the opposite tower, down to the lifting-bracket on the span. With the gearing provided, one man can raise the span to its full height without difficulty.

Telegraph Point Bridge.—This bridge (Fig. 16, Plate 4), which has been recently erected over one of the smaller coastal rivers, embraces an opening-span of the bascule type, counter-balanced ...inciple which has been applied in several structures in the

United States, but is new to Australia. A lifting-span of the Cobram type just described would not be suitable for this bridge as provision has to be made for the passage of masted vessels.

The principle involved in the design of this span is the following:—When a bascule-span is at the commencement of its lift, its weight acts with a leverage equal to the distance between the centre of gravity of the span and the centre of the hinge or trunnion on which it is pivoted. As the span rises, the path of its centre

Fig. 15.



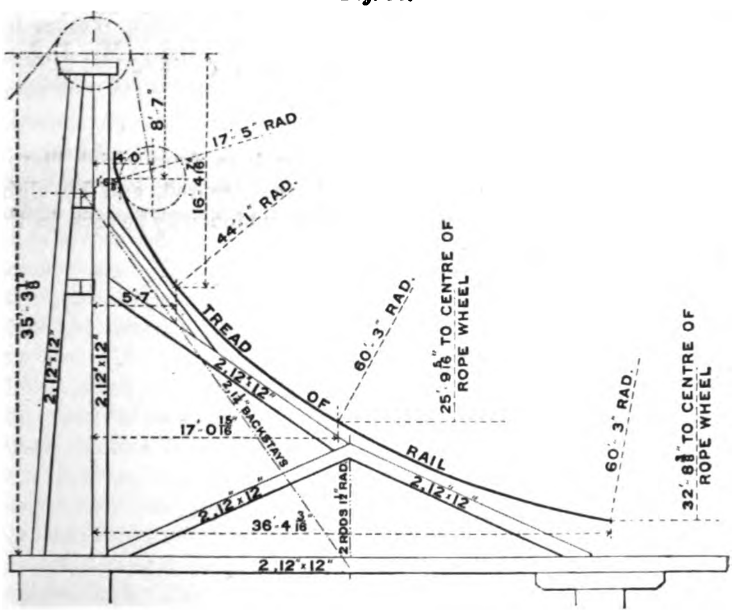
TYPE OF STEEL LIFTING-SPAN.

of gravity lies on a circle described with the hinge as its centre, and thus the leverage and moment of the weight of the span, and consequently the amount of balance-weight required, diminish during the operation of lifting. In the Telegraph Point Bridge the variation in the moment of the weight of the span as it is lifted is provided against by causing the balance-weights to roll down curved tracks, so designed that the vertical component of the balance-weights is a continually decreasing quantity. At any point during the lift this vertical component of the balance-

weights represents the tension in the ropes connecting them to the opening span, and the moment of the tension on the ropes about the centre of the hinge is equal to the moment of the weighs of the span about the same point. This ensures an even balance throughout the lift. The opening-span consists of a pair of steel plate-web girders, 3 feet in depth, connected by cross-girders at intervals of 14 feet 3 inches, and also by diagonal-bracing between the lower flanges. The deck is of timber, and is 14 feet in width. The clear opening provided is 40 feet between the guide-walings when the span is raised. The weight of the span was estimated at 42,600 lbs., and the amount of balance-weight required at 44,740 lbs., while the total rise of the centre of gravity of the span in opening is 23 feet, and the total fall of the balance-weight is 21 feet 10¾ inches. It was found during erection that the amount of balance-weight actually required was 1,380 lbs. less than that estimated for, due to a variation in the weight of the timber employed for the deck. The balance-weights, which are of cast-iron (Figs. 17, Plate 4), travel each on a pair of 45-lb. rails secured to timber sleepers on the timbers of the back truss-span, as shown in Fig. 16, Plate 4. A number of small adjustable weights are provided on each balance-weight to give exact balance, as required from time to time. The curve required for the track (*Fig. 18*) was set out graphically and checked by calculation. The rails forming the curved track are each in three lengths, bent cold to the different radii shown, and connected together by fish-plates. As the funds at disposal did not permit of the use of steel towers, these have been constructed each of four hewn ironbark timbers, braced together, and the trusses carrying the track are also built of ironbark. This forms a very stout structure, and it is not anticipated that any difficulty will be found in renewing portions of it when required, but in three other bascule-bridges of this type, now under construction, in which larger opening-spans, viz. 60 feet in the clear, are required, the towers and trusses for the tracks are all being constructed of steel. At the top of each tower there is a cast-iron rope-wheel 5 feet in diameter, grooved to receive the three steel wire-ropes which connect each balance-weight to the lifting-bracket on the opening-span. Each of these ropes, which are 3½ inches in circumference, consists of six strands, having thirty-seven wires in each strand, and has a breaking-strength of 36 tons. One end of each rope is spliced round a cast-iron thimble, on the cradle for the balance-weight, and the other end is secured by an adjustable connection to the lifting-bracket on the span. It was originally

intended to operate the span by means of worm-gearing, at deck-level, working a vertical shaft gearing on to the horizontal shaft carrying the rope-wheels; but, owing to the excessive friction of the worm-gearing, this was abandoned, and spur-gearing, operated from a platform near the top of the tower, has been substituted. This has proved very successful, one man being able to raise the span to its full height with the greatest ease in 4 to 5 minutes, whilst the operation of closing occupies about the same time, the working of the span being smooth and uniform throughout. The 45-foot side-spans are of the compound beam type, and Monier

Fig. 18.



cylinders have been used throughout, sunk by means of divers. The work has been carried out by day-labour at a cost of £8,500 under Mr. W. F. Burrow, Assoc. M. Inst. C.E., Resident Engineer.

According to the 1901 census the population of New South Wales is about 1,360,000 persons, spread over an area of 310,700 square miles. Large areas are still sparsely populated, but settlement is steadily increasing, and £500,000 to £750,000 per annum is spent by the Government in the maintenance and construction of roads and bridges. At the present time the traffic in many instances is not sufficient to justify the erection of a bridge, and

punts working on wire-ropes stretched from bank to bank are employed, operated by hand-power, or, in the case of the more important ferries, by steam. No steel road-bridges of the large spans used in the United States and elsewhere have been hitherto found necessary in the State, but it is probable that in the future, when the tidal estuaries of the coastal rivers have to be bridged, some of these may be required.

The bridges described in the foregoing have been designed by the Author, acting under Mr. E. M. de Burgh, M. Inst. C.E., Engineer for Bridges, to whom he is indebted for assistance and advice. The Author is also indebted to Mr. W. J. Hanna, Commissioner and Principal Engineer for Roads and Bridges, and Mr. J. Davis, M. Inst. C.E., Under Secretary for Public Works, for permission to use the plans of the Department; and to Mr. J. J. C. Bradfield, Assoc. M. Inst. C.E., and Mr. C. Hodgson, for assistance in the design of the works referred to.

The Paper is accompanied by three tracings, from which Plate 4 and the Figures in the text have been prepared, and by eight photographs and twenty-nine sunprints, which may be seen in the library of the Institution.

(*Paper No. 3423.*)

"Copper Locomotive-Boiler Tubes."

By FRANCIS WILLIAM WEBB, Vice-President Inst. C.E.

HAVING recently concluded an investigation made with the object of determining the composition of copper tubes most suitable for use in locomotive-boilers, the Author has pleasure in presenting the result, which, he feels sure, will be interesting, and doubtless useful, to engineers engaged in locomotive-work. As mentioned in his Paper[1] on "Locomotive Fire-box Stays," the fire-box stays of the locomotive-boilers on the London and North Western Railway are of copper; the inner casing of the fire-box and the tubes generally are also of that metal, which is found to be more economical than steel, in respect of both durability and evaporative power.

Soon after the general introduction of copper boiler-tubes it was observed that certain tubes had a much longer life than others; in fact the life of tubes by the same maker often varied considerably. Chemical analyses of both good and bad tubes were made from time to time, and it was generally found that the most durable tubes contained some hardening-element, such as arsenic or nickel; and also that the life of a tube depended upon how it had been worked. The tubes usually fail through being worn thin by the corrosive action of the furnace-gases and the abrasion of the cinders, the pressure inside the boiler then causing them to collapse at the corroded part. Others fail by breaking immediately behind the fire-box tube-plate, a result which is often due to brittleness.

In order to ascertain the composition of the copper tubing most suitable for use in locomotive-boilers, a set of tubes (198) by ten different makers, namely, twenty by each of eight makers and nineteen by each of two makers, was put into the boiler of engine

[1] Minutes of Proceedings Inst. C.E., vol. cl. p. 87.

No. 1,213, "The Queen," a 4-wheels-coupled passenger-engine. Each make of tube was so placed in the tube-plate as to get the same amount of abrasion by cinders and corrosion by furnace-

Fig. 1.

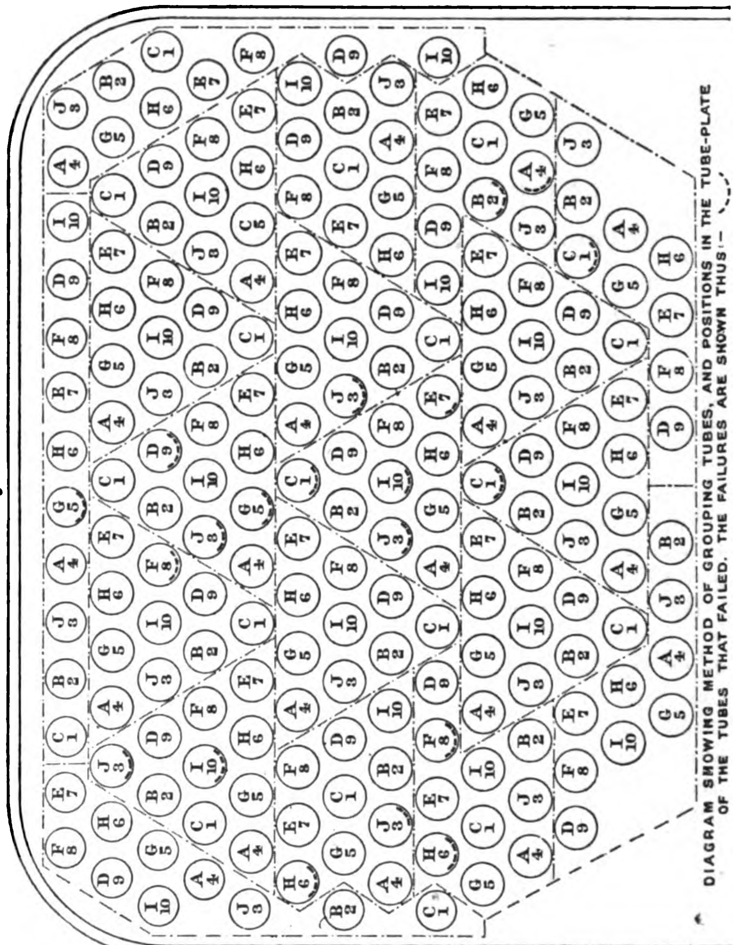


DIAGRAM SHOWING METHOD OF GROUPING TUBES, AND POSITIONS IN THE TUBE-PLATE OF THE TUBES THAT FAILED. THE FAILURES ARE SHOWN THUS:-

gases; this was insured by arranging them in twenty groups, each group containing one tube of each make, with two exceptions, in which nine makers only were represented in each group. The method of grouping is illustrated in *Fig. 1.* The tubes were numbered consecutively 1 to 198, and the different makes were numbered 1 to 10.

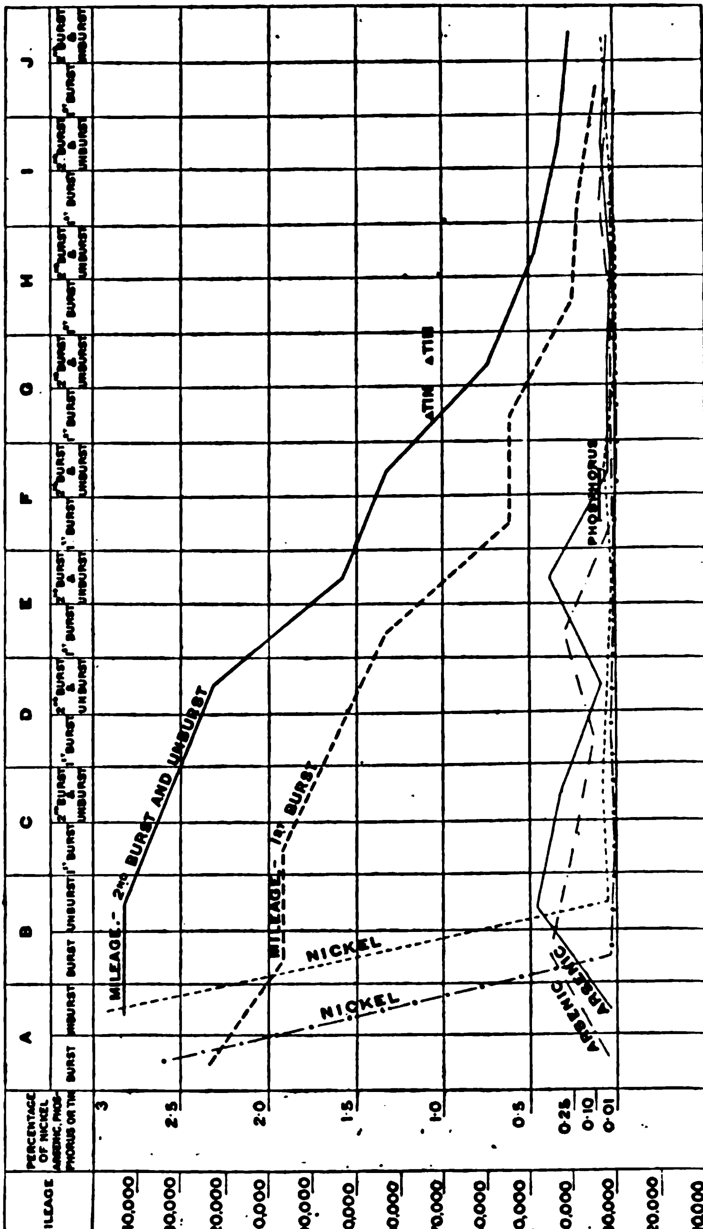
The boiler fitted with the experimental set of tubes commenced work in October, 1898, and finished in December, 1901. During that time the engine ran 142,348 miles. In order to determine the relative merit of each make of tube the following rule was observed. When a tube failed, it was taken out of the boiler and the mileage of the engine was noted; and when a second tube of the same make failed, the whole of the tubes of that make were removed from the boiler and the engine-mileage up to the failure of the second tube was noted. While the experiment was in progress, the tubes were re-rolled and re-ferruled and the ferrules were knocked up several times.

The first tube failed after the engine had completed 34,067 miles, and the second tube of the same make at the end of 40,612 miles; whereas the first and only failure of the make which stood the best did not take place until the engine had completed 123,896 miles. Of the tubes second in order of merit, only one tube failed, and that at the end of 107,507 miles. When the engine had completed 142,348 miles, it was decided to stop the experiment, although the experimental tubes remaining in the boiler, by two makers, were still in fairly good condition.

It was observed that, with one exception, the failure of the tubes was due to their having worn thin from the inside, invariably at the bottom and within 6 inches of the fire-box end of the tube, the pressure inside the boiler causing them to collapse. The one exception was that of a tube which cracked during re-rolling. It is singular that the inside of the tubes should invariably wear thin at the bottom. Doubtless, this unequal wasting of the tube is due either to the sulphurous acids from the sulphur in the coal condensing on the bottom of the tube near the fire-box end during the lighting-up of the boiler, and thus corroding the metal; or to a portion of the cinders striking the top, inside of the ferrule, and being deflected downwards against the bottom of the tube. A typical example showing the unequal wasting of the tube just beyond the ferrule is illustrated in Fig. 2, Plate 5; and the shape and thickness of a typical "burst" tube are shown in Fig. 3, Plate 5.

Chemical analyses of each of the tubes that failed, and of the average of the tubes that did not fail, were made. The results of the analyses, together with the mileage of each make of tube, arranged in order of mileage—and therefore of merit—(A to J) are set out in Table I. of the Appendix, and are shown diagrammatically in *Fig. 4*. It will be observed that there is practically no difference in the chemical composition of tubes of the same

Fig. 4.


MILEAGE
PERCENTAGE OF NICKEL ARSENIC, PHOSPHORUS OR TIN
A
B
C
D
E
F
G
H
I
J
BURST
UNBURST
1ST BURST
2ND BURST & UNBURST
MILEAGE.- 2ND BURST AND UNBURST
MILEAGE.- 1ST BURST
NICKEL
NICKEL
ARSENIC
ARSENIC
PHOSPHORUS
140,000
130,000
120,000
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
3
2·5
2·0
1·5
1·0
0·5
0·25
0·10
0·01

make, whether they failed or not; and that the two makes of tubes which stood the best are hardened with nickel and arsenic respectively. Of the tubes marked C in order of merit, two failed (Nos. 146 and 178) at the same time; hence, three tubes of this make are shown as having failed.

Taking the quantity of arsenic present as determining the hardness of the tube, and the hardness as representing its life, the tubes E in Table I. should, at least, be one place higher in order of merit. However, the make which stood the best is quite different from the others in chemical composition.

The Author thinks it will be agreed, as the result of this investigation, that the most satisfactory copper tubes for locomotives are those containing either 3 per cent. of nickel, or at least 0·5 per cent. of arsenic.

Copper tubes hardened with nickel are now being put into locomotives on the London and North Western Railway, and good results are anticipated from them.

Three samples of seamless copper tubes, said to contain 3 per cent. of nickel, 0·5 per cent. of arsenic and 0·75 per cent. of arsenic, respectively, which have been made as the outcome of the foregoing investigation, have been submitted to the Author. A complete chemical analysis of each of these tubes is given in Table II., and the results of the mechanical tests of the samples in Table III. of the Appendix. These mechanical tests indicate that the tubes are softer than the average of thirty-two samples of ordinary copper tube taken from consignments received from time to time. Nevertheless, on cutting them with a chisel they do not show particularly soft metal, especially in the case of the sample marked N 3.

Some time ago experiments were conducted at Crewe with fluted copper tubes (Figs. 5, Plate 5); but it was found that the ridges inside the tube suffered abrasion, especially at the commencement of the ridges, just beyond the ferrule, which were rather quickly worn through; consequently the use of such tubes had to be abandoned.

An ordinary copper tube which has suffered abrasion rather severely, as will be seen from the corrugated appearance of the inside surface of the tube, is illustrated in cross-section in Fig. 6, Plate 5.

In conclusion, a form of steel ferrule, introduced by the Author at Crewe some time ago, may be mentioned. The ferrules, which are stamped from mild-steel sheet, are, in the fourth of the five operations of manufacture, forced into a die which forms sixteen

small ridges, $\frac{1}{16}$ inch in width and about $\frac{1}{64}$ inch in depth on the outside. These ferrules, having a taper of 1 in 80, in addition to the ridges, are found to hold better in the ends of the tubes, which are rolled with parallel sides, than the plain turned ferrules with a taper of 1 in 40. An elevation and an end-view of this improved ferrule are shown in Fig. 7, Plate 5.

The Paper is accompanied by two diagrams and six photographs, from which Plate 5 and the Figures in the text have been prepared; and by the following Appendix.

[APPENDIX.

APPENDIX.

TABLE I.—CHEMICAL COMPOSITION AND MILEAGE OF A SET OF 198 COPPER LOCOMOTIVE-BOILER TUBES, MADE UP FROM TUBES SUPPLIED BY TEN DIFFERENT MAKERS.

Order of Mileage (A to J).	A		B		C				D			E		
Number of Make	4		2		1				9			7		
Ref. No. on Tube	166 [1]	[2]	151 [1]	[2]	84 [1]	146 [1]	178 [1]	[2]	33 [1]	38 [1]	[2]	132 [1]	187 [1]	[2]
Tin	absent	absent	0·02	trace	trace	absent	absent	absent	absent	absent	absent	absent	mere trace	absent
Antimony	trace	trace	0·016	0·02	0·021	0·019	0·013	0·02	0·01	0·006	trace	0·012	0·017	0·02
Arsenic	0·03	0·05	0·40	0·46	0·25	0·32	0·34	0·34	0·11	0·08	0·095	0·30	0·38	0·43
Lead	absent	absent	absent	trace	absent	trace	0·11	0·03	absent	absent	mere trace	absent	absent	trace
Bismuth	"	"	"	absent	"	absent	trace	mere trace	"	"	absent	"	"	absent
Iron	trace	trace	trace	trace	trace	"	"	trace	"	trace	"	trace	trace	mere trace
Chromium	absent	absent	absent	absent	absent	"	absent	absent	"	absent	"	absent	absent	absent
Aluminium	"	"	"	"	"	"	"	"	"	"	"	"	"	"
Manganese	"	"	"	"	"	"	"	"	"	"	"	"	"	"
Nickel	2·66	2·90	0·04	0·05	0·01	0·08	0·02	0·03	0·02	0·06	0·03	0·02	0·02	0·92
Cobalt	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent
Zinc	"	"	"	"	"	"	"	"	"	"	"	"	"	"
Sulphur	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace
Phophorus	0·033	0·033	absent	mere trace	absent	absent	absent	mere trace	"	"	mere trace	0·006	"	absent
Silver	absent	absent	trace	absent	"	"	"	absent	absent	"	trace	absent	"	mere trace
Copper (by diff.)	97·277	97·017	99·524	99·470	99·719	99·581	99·517	99·580	99·860	99·854	99·875	99·662	99·583	99·530
Total	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000
Mileage	123,896	142,348	107,507	142,348	107,507	133,112			95,456	123,896		82,327	93,475	

[1] Analysis of tubes which failed.

[2] Average composition of tubes which did not fail.

TABLE I.—*continued.*

Order of Mileage (A to J)	F			G			H			I			J		
No. of Make	8			5			6			10			3		
Ref. No. on Tube.	36[1]	126[1]	[2]	68[1]	7[1]	[2]	77[1]	124[1]	[2]	48[1]	115[1]	[2]	109[1]	53[1]	[2]
Tin . .	absent	absent	absent	1·05	1·09	1·07	trace	trace	absent	0·03	trace	absent	absent	absent	absent
Antimony	trace	0·01	0·01	0·01	0·008	trace	,,	0·01	trace	0·01	0·005	trace	0·01	0·01	mere trace
Arsenic .	0·03	0·04	0·04	0·04	0·03	0·04	0·02	0·03	0·04	0·08	0·06	0·06	0·03	0·04	0·04
Lead . .	absent	absent	absent	absent	absent	absent	absent	absent	absent	0·03	0·03	0·03	absent	trace	trace
Bismuth .	,,	,,	,,	,,	,,	,,	,,	,,	,,	absent	absent	absent	,,	absent	absent
Iron . .	,,	trace	,,	trace	,,	trace	,,	trace	trace	trace	trace	mere trace	trace	trace	mere trace
Chromium	,,	absent	,,	absent	,,	absent	,,	absent	absent	absent	absent	absent	absent	absent	absent
Aluminium	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,
Manganese	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,
Nickel .	0·01	trace	0·04	trace	trace	0·03	trace	trace	0·01	0·02	0·03	trace	,,	trace	0·09
Cobalt .	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	,,	absent	absent
Zinc . .	,,	,,	,,	,,	,,	,,	,,	trace	,,	,,	,,	,,	,,	trace	,,
Sulphur .	trace	trace	trace	trace	trace	trace	trace	,,	trace	trace	trace	trace	trace	,,	trace
Phosphorus	0·095	0·092	0·088	0·021	0·015	0·018	0·041	0·025	0·044	absent	absent	mere trace	absent	absent	,,
Silver . .	absent	absent	mere trace	absent	absent	absent	absent	absent	absent	,,	trace	trace	,,	,,	absent
Copper (by diff.)	99·865	99·858	99·882	98·879	98·857	98·842	99·939	99·935	99·906	99·830	99·875	99·910	99·960	99·950	99.870
Total .	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000
Mileage	55,634	82,327		54,466	59,028		40,612	48,809		39,760	43,230		34,067	40,612	

[1] Analysis of tubes which failed.

[2] Average composition of tubes which did not fail.

TABLE II.—THREE SEAMLESS COPPER TUBES.

CHEMICAL ANALYSES.

—	Sample Marked 1902. ·5	Sample Marked 1902. ·75	Sample Marked 1902. N. 3
	Per Cent.	Per Cent.	Per Cent.
Arsenic	0·58	0·80	trace
Antimony	trace	0·01	„
Nickel	0·06	0·06	3·10
Iron	trace	trace	0·08
Phosphorus	absent	absent	0·04
Lead	0·08	0·08	absent
Sulphur	trace	trace	trace
Copper (by diff.)	99·28	99·05	96·78
	100·00	100·00	100·00

TABLE III.—THREE SEAMLESS COPPER TUBES.

MECHANICAL TESTS.

(1) *Span Test (tube supported on centres* 10 *feet apart, and loaded at middle).*

Mark on Tube.	Diameter.	Thickness.	Load Required to Produce the First Permanent Set.			Load Required to Produce a Permanent Set of $\frac{1}{10}$ inch.		
			Load.	Deflection.	Permt. Set.	Load.	Deflection.	Permt. Set.
	Inch.	Inch.	Lbs.	Inch.	Inch.	Lbs.	Inch.	Inch.
1902. ·5	1·86	0·14	80	0·66	0·01	180	1·56	0·10
„ ·75	1·86	0·14	60	0·51	0·01	225	1·94	0·10
„ N. 3	1·86	0·14	60	0·48	0·01	210	1·68	0·10
Mean of 32 previous tests made with ordinary copper tubes	1·87	0·12	128	1·09	0·01	273	Inches. 2·40	0·10

(2) *Tensile Test (on tubes as received from makers).*

Mark on Tube.	Diameter.	Thickness.	Area.	Breaking Weight.	Contraction of Area.	Extension on 6 Inches.	Remark.
	Inch.	Inch.	Sq. Inch.	Tons per Sq. Inch.	Per Cent.	Per Cent.	
1902. ·5	1·86	0·14	0·756	15·87	61·6	36·3	Extension uniform over the tube.
„ ·75	1·86	0·14	0·756	16·00	57·4	34·8	
„ N. 3	1·86	0·14	0·756	17·39	70·6	31·3	
Mean of 32 previous tests	1·87	0·12	0·660	20·19	50·3	9·8	

TABLE III.—MECHANICAL TESTS—*continued.*

Drifting Tests.

Mark on Tube.	Diameter. Inch.	Thickness. Inch.	Maximum Diameter, Drifted. Inches.	Increase in Diameter. Inch.	Expansion. Per Cent.	Remark.
(3 A.) *On Tubes as received from Makers.*						
1902. ·5 . .	1·86	0·14	3·04	1·18	63·5	
„ ·75. .	1·86	0·14	3·00	1·14	61·3	
„ N.3 .	1·86	0·14	3·24[1]	1·38	74·2	
Mean of 32 previous tests .	1·87	0·12	2·10	0·23	12·3	
(3 B.) *On Tubes annealed and cooled in Air.*						
1902. ·5 . .	1·86	0·14	3·24[1]	1·38	74·2	
„ ·75. .	1·86	0·14	3·02	1·16	62·4	[1] Did not burst.
„ N.3 .	1·86	0·14	3·24[1]	1·38	74·2	
Mean of 32 previous tests .	1·87	0·12	2·91	1·04	55·6	
(3 C.) *On Tubes annealed and cooled in Water.*						
1902. ·5 . .	1·86	0·14	3·24[1]	1·38	74·2	
„ ·75. .	1·86	0·14	3·24[1]	1·38	74·2	
„ N.3 .	1·86	0·14	3·24[1]	1·38	74·2	
Mean of 32 previous tests .	1·87	0·12	2·84	0·97	51·9	

(4.) *Rolling Test in Tube-Plate.*

Unannealed . . . . . . All three tubes work very well.
Annealed . . . . „ „ „ „ „ „

(*Paper No. 3481.*)

"Differences in Structure of certain of the Steel Plates experimented on by Professor Unwin, as described in his Paper on 'Tensile Tests of Mild Steel.'"

A note communicated from the National Physical Laboratory.

REFERENCE was made in Professor Unwin's recent Paper,[1] read at the Institution, to the difference in tensile strength between the thick and the thin plates on which he experimented, and the suggestion was made that the microscope would show a difference in structure produced by the additional work put into the thin plate, which possibly might be connected with this variation in tensile strength. Professor Unwin kindly placed at the disposal of the National Physical Laboratory two of the test-bars used in his experiments, and on these the observations recorded in this Note have been made by Dr. Carpenter and Mr. L. F. Richardson.

EXAMINATION OF TEST-BARS 2348 AND 2354.

Part of the difference between the elongation obtained with thick and with thin plates, observed by Professor Unwin, may be accounted for by the difference in composition of the plates. The percentage of carbon, as given in Professor Unwin's Paper, is 0·185 per cent. in the 1¼-inch plate, and 0·145 per cent. in the ⅜-inch plate; and the percentages of elongation for plates containing 0·32 per cent. of carbon are:—

For a ¼-inch plate	23·8 per cent.
" ½ " "	20·7 " "
" ¾ " "	18·7 " "

From these the following percentage elongations for plates containing 0·32 per cent. of carbon may reasonably be deduced:—

$$\text{For a } \tfrac{3}{8}\text{-inch plate, } \frac{23 \cdot 8 + 20 \cdot 7}{2} = 22 \cdot 25 \text{ per cent.}$$

$$\text{,,} \quad \tfrac{5}{8} \quad \text{,,} \quad \text{,,} \quad \frac{20 \cdot 7 + 18 \cdot 7}{2} = 19 \cdot 7 \quad \text{,,} \quad \text{,,}$$

[1] *Ante*, p. 170.

But the elongations of plates containing about 0·16 per cent. of carbon are:—

For a $\frac{3}{8}$-inch plate	30·8 per cent.
„ $\frac{5}{8}$ „ „	26·7 „ „

Thus a difference of 0·16 per cent. of carbon causes differences of 7·5 per cent. and 7·0 per cent. elongation in the $\frac{3}{8}$-inch and $\frac{5}{8}$-inch plates respectively. Therefore a variation between 0·185 per cent., and 0·145 per cent. of carbon, or a difference of 0·04 per cent., may be expected to cause about one-quarter of this difference in elongation, viz. 1·8 per cent., in the direction found by Professor Unwin.

It is also stated that the thick plate contains 0·19 per cent. more manganese than the thin plate, but there are no data in the Paper from which an estimate of its influence can be made.

Pieces were cut from the test-bars in the positions indicated in Figs. 1 and 2, Plate 6.

The polished surfaces of A, B, C, *a*, *b*, *c*, were perpendicular to the surface of the plate and parallel to the length of the test-bar. The polished surfaces of D and *d* were parallel to the surface of the plate. In all cases the face towards the inside of the bar was the polished face.

A and *a* were chosen to show the structure of the unstrained plate. B and *b* were chosen to show the structure after general elongation. C and *c* were chosen to show the effect of local elongation near the fracture.

The polished faces were etched for 7 minutes with 5 per cent. picric acid in absolute alcohol. This treatment differentiates between the two structural constituents of the material, making the pearlite dark and leaving the ferrite bright when seen under vertical illumination.

All the photographs (Figs. 3–16, Plate 6) were taken at a magnification of 150 diameters. The pearlite was examined at a magnification of 1,000 diameters, and was found to be obscurely granular, instead of banded, as is usual in pure carbon-iron alloys. This, no doubt, is due to the presence of the 0·5 to 0·7 per cent of manganese.

Professor Unwin's suggestion, that the grains of the thick and thin plates differ in size, is amply borne out by the photo-micrographs shown. In sections perpendicular to the surface of the plate, viz. A, B, C, *a*, *b*, *c*, the pearlite areas in the thin plate appear considerably thinner than those in the thick plate, without being noticeably longer, Figs. 3–12, Plate 6. In sections D and *d* cut parallel to the surface of the plate, the pearlite areas appear

smaller in the thin plate than in the thick one, Figs. 13 and 14, Plate 6. From this it is clear that the pearlite grains are broken up in rolling.

There is no appreciable difference between the structure of the surface and that of the interior of any of the specimens examined, except that within 0·25 millimetre ($\frac{1}{100}$ inch) of the surface there is rather less pearlite.

The strained and unstrained sections of the thin plate are indistinguishable. In the case of the thick plate the strained section C (Figs. 9 and 11, Plate 6) showed a more parallel arrangement of the pearlite grains than the unstrained section A (Figs. 3 and 5, Plate 6). Ewing and Rosenhain have shown[1] that the plastic yielding of pure metals, when strained beyond the elastic limit, takes place by slipping along gliding-planes in the crystals, so that the breaking-up of the pearlite affords in itself no reason for expecting a change in the elongation, until the effect of rolling on the position and concentration of the gliding-planes in the metal is known. In the case of very mild steel, Ewing and Rosenhain observed "that the first effect of strain is to develop the inter-granular junctions in the ferrite areas; then more severe strain makes the slip-bands appear"; but they were not able "to observe anything of the nature of slip-bands in the dark or pearlite areas of steel," and although, on grounds of analogy with other eutectics, they state that it is possible that pearlite may yield plastically by slipping, this is meant to apply to banded, well-segregated pearlite, and not to the granular variety.

The structure of pieces (E and *e*) from the enlarged ends of the two bars, after annealing for an hour at a temperature of 1,230° C. to 1,320° C., is shown in Figs. 15 and 16, Plate 6. The polished surfaces were perpendicular to the surface of the plate. They show that the rolled structure has completely disappeared. The section from the thin plate shows less pearlite. Annealing for an hour at 1,000° C. to 1,020° C. failed to produce this result.

The Paper is accompanied by a drawing and four sheets of photographs, from which Plate 6 has been prepared.

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[1] Philosophical Transactions, A., vol. cxciii. pp. 353–372.

(*Paper No. 3345.*)

"Line Effects in Long-distance Transmission of Power by Electricity."

By HENRY JAMES SHEDLOCK HEATHER, B.A., Assoc. M. Inst. C.E.

IN practice, the problems to be solved in designing lines for the transmission of power by electricity over long distances differ from those met with in dealing with short lines, not only in the magnitude of the quantities involved, but also in the nature of the considerations that have to be taken into account; and the differences are seen both from the technical and from the commercial point of view.

In the early days of power-transmission, when only continuous currents and what are now regarded as very low voltages were thought of, both efficiency of transmission and facility of regulation were secured by using large quantities of copper, the drop in voltage and the loss in watts on the line both depending solely on its electrical resistance. Interesting calculations were made in order to ascertain the most favourable relation to be observed between the horse-power to be transmitted and the cost of the copper. This relation was modified by the inclusion of a factor representing the cost of the insulation of the copper, and the line problem was solved, the attainment of a fairly high efficiency itself rendering small the range over which regulation would be required. The distance to which transmission could be economically effected was limited by the maximum voltage for which continuous-current machines could be built, for it was of course recognized that line-losses were reduced by increasing the voltage.

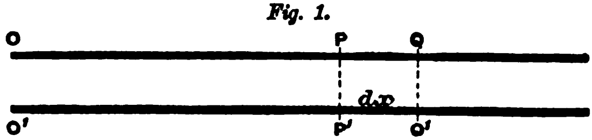
The knowledge that by using alternating currents much higher voltages could be rendered practically available was not of much use in extending the limits of transmission of power, owing to the absence of a reliable alternating-current motor. When the development of polyphase motors and polyphase distribution removed this obstacle it was at first thought that the distance to which electrical power could be transmitted would in the future be limited only by the maximum voltage for which machinery

could be built, exactly as had been found to be the case for continuous currents. Difficulties, however, of the same nature as those met with in cable-telegraphy, were soon encountered when underground cables were used; but as, owing to the high cost of cables, long-distance power-transmission had to be carried out by means of overhead lines, on which the effect of the complicating factors was of much less relative importance, there was, perhaps, a tendency to under-estimate these difficulties, which may become very serious when transmission to a distance of 100 miles or more is under consideration.

The fact that it is found advisable in alternating-current power-transmission so to design the generators and motors that the voltage and the current may vary harmonically, their instantaneous values, when plotted as ordinates to a time-base, giving as nearly as possible true sine-curves, has rendered it practicable to calculate accurately instantaneous values for the voltage and current at one end of any given line in terms of the values at the other end. The properties of the line, in addition to the length and the resistance per unit of length, which have to be known in order to do this, are the coefficient of self-induction and the capacity per unit of length. Both of these, as will be seen later, are directly derivable from the geometric data of the line.

Consider an elementary length dx of a pair of parallel wires, *Fig. 1*:—

Fig. 1.



Let PP^1 be one extremity of the elementary length.

Let QQ^1 be the other extremity,

and let OO^1 represent the ends of the wires at which the power is to be delivered.

Then, denoting OP by x

$$OQ = x + dx,$$

and at the point where the power is delivered $x = 0$.

Let v_x denote the voltage between P and P^1;

then v_{x+dx} is the voltage between Q and Q^1.

If i_x denote the current along the wires at P, i_{x+dx} is the current along the wires at Q.

If l, r and c denote respectively the self-induction, resistance, and capacity per unit of length of the system of two wires, ldx

$r dx$, and $c dx$ will be the values for the element under consideration.

Then the current along the wire at P, together with the current absorbed between P and Q by the effect of the capacity between PQ and P^1Q^1, must be equal to the current along the wire at Q. The current absorbed by this capacity is equal to the capacity multiplied by the rate of change of the voltage between the wires; that is, to $c\,dx\,\frac{dv_x}{dt}$.

Therefore $$i_{x+dx} = i_x + c\,dx\,\frac{dv_x}{dt} \quad . \quad . \quad . \quad . \quad (1)$$

Also, the decrease in voltage difference along the wires is $v_{x+dx} - v_x$, and this is equal to the sum of the ohmic drop and that due to the electromotive force of self-induction; that is, to

$$l dx \frac{di_x}{dt} + r\,dx . i_x.$$

So that

$$v_{x+dx} - v_x = l\,dx \cdot \frac{di_x}{dt} + r\,dx \cdot i_x \quad . \quad . \quad . \quad (2)$$

But $$\frac{i_{x+dx} - i_x}{dx} = \frac{di_x}{dx}$$

and $$\frac{v_{x+dx} - v_x}{dx} = \frac{dv_x}{dx}.$$

Therefore $$\frac{di_x}{dx} = c\frac{dv_x}{dt} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and $$l\frac{di_x}{dt} + r i_x = \frac{dv_x}{dx} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

From these two equations the following can be at once deduced:—

$$c l \frac{d^2 v_x}{dt^2} + c r \frac{dv_x}{dt} = \frac{d^2 v_x}{dx^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

and $$c l \frac{d^2 i_x}{dt^2} + c r \frac{di_x}{dt} = \frac{d^2 i_x}{dt^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

These two differential equations have exactly the same form. That for v_x will be first considered.

It is known that the voltage across the points $O\,O^1$ (for which $x = 0$) can be represented by an expression of the form

$$V \sin p t$$

where t represents time, p is 2π times the number of complete cycles per second, and V is the maximum voltage at the crest of

the sine-curve wave. If the current at this point lags behind the volts by a fraction of the time of a complete cycle represented by $\frac{\phi}{2\pi}$, the current at this point can, in the same way, be represented by I sin $(p\,t - \phi)$, where I is its maximum value.

All expressions of the form

$$\epsilon^{a\,t + b\,x}$$

satisfy equation (5), if a and b are subject to the relation

$$c\,l\,a^2 + c\,r\,a = b^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

The general solution, therefore, is the sum of all terms of such form, each multiplied by an arbitrary constant, the relation expressed by equation (7) being adhered to by the coefficients of t and x in every term. No assumption has to be made as to whether a and b are real or otherwise; it is therefore necessary to consider that each may contain an imaginary as well as a real part.

At the point O O[1], where $x = 0$, the general solution has to assume the form

$$\text{V} \sin p\,t;$$

that is

$$\frac{\text{V}}{2\sqrt{-1}}\left(e^{\sqrt{-1}.p.t} - e^{-\sqrt{-1}.p.t}\right)$$

This shows that only two values of a, namely, $\sqrt{-1}.p$ and $-\sqrt{-1}.p$, need be retained. Corresponding to any one value of a, there are two values of b, equal in magnitude, but opposite in sign; that this is so is shown by equation (7).

Consequently, in all, four terms have to be retained in the general solution of equation (5), which accordingly becomes—

$$\left.\begin{aligned} v_x &= \text{A}_1\, e^{\sqrt{-1}.p.t + \sqrt{-c l p^2 + c r p \sqrt{-1}}.x} \\ &+ \text{A}_2\, e^{\sqrt{-1}.p.t - \sqrt{-c l p^2 + c r p \sqrt{-1}}.x} \\ &+ \text{A}_3\, e^{-\sqrt{-1}.p.t + \sqrt{-c l p^2 - c r p \sqrt{-1}}.x} \\ &+ \text{A}_4\, e^{-\sqrt{-1}.p.t - \sqrt{-c l p^2 - c r p \sqrt{-1}}.x} \end{aligned}\right\} \quad . \quad . \quad (8)$$

By similar reasoning, remembering that i_x at the point O has to be I sin $(p\,t - \phi)$, from equation (6) can be obtained an expression for i_x similar to the foregoing expression for v_x, but differing in that $p\,t - \phi$ occurs in it in place of the $p\,t$ in the value for v_x, and that the arbitrary constants are of course different. Comparing these values for v_x and i_x with the relations (3) and (4), and remembering their respective values V sin $p\,t$ and

I sin $(pt - \phi)$ at the point for which $x = 0$, all the constants may be determined in terms of known quantities, and finally the equations are obtained in the forms:—

$$\left.\begin{aligned} v_x = &\left\{\frac{V}{2} - \frac{I}{2\,cp}\Big(\beta\cos\phi - a\sin\phi\Big)\right\} e^{-ax}\sin(pt - \beta x) \\ &+ \left\{\frac{V}{2} + \frac{I}{2\,cp}\Big(\beta\cos\phi - a\sin\phi\Big)\right\} e^{ax}\sin(pt + \beta x) \\ &+ \frac{I}{2\,cp}\Big(a\cos\phi + \beta\sin\phi\Big) e^{-ax}\cos(pt - \beta x) \\ &- \frac{I}{2\,cp}\Big(a\cos\phi + \beta\sin\phi\Big) e^{ax}\cos(pt + \beta x) \end{aligned}\right\} \quad (9)$$

$$\left.\begin{aligned} i_x = &\left\{\frac{I}{2} - \frac{V}{2\sqrt{r^2+p^2l^2}}\Big(\beta\cos\phi - a\sin\phi\Big)\right\} e^{-ax}\sin(pt - \beta x - \phi) \\ &+ \left\{\frac{I}{2} + \frac{V}{2\sqrt{r^2+p^2l^2}}\Big(\beta\cos\phi - a\sin\phi\Big)\right\} e^{ax}\sin(pt + \beta x - \phi) \\ &- \frac{V}{2\sqrt{r^2+p^2l^2}}\Big(a\cos\phi + \beta\sin\phi\Big) e^{-ax}\cos(pt - \beta x - \phi) \\ &+ \frac{V}{2\sqrt{r^2+p^2l^2}}\Big(a\cos\phi + \beta\sin\phi\Big) e^{ax}\cos(pt + \beta x - \phi) \end{aligned}\right\} \quad (10)$$

in which

$$a = \sqrt{\frac{cp}{2}\left(\sqrt{r^2+p^2l^2} - pl\right)} \quad . \quad . \quad . \quad (11)^1$$

$$\beta = \sqrt{\frac{cp}{2}\left(\sqrt{r^2+p^2l^2} + pl\right)} \quad . \quad . \quad . \quad (12)^1$$

These equations give full particulars of the voltage and current at any point of the line; that is to say, they give magnitudes and phases of both in terms of those at the origin, *i.e.* of those required at the point where the power is to be delivered. The phase-difference between the volts and the amperes at the power-station is also therefore deducible for any given load. It is shown by the form of the equations that the volts and amperes follow a wave law with respect to distance, x, as well as with respect to time, t, although further investigation reveals that, even in the case of transmission to a distance of 200 or 300 miles, only a small portion of the first wave-length is covered. This is shown by a quantitative

[1] Since this Paper was written the Author has learned that these and the preceding general results are not novel; similar expressions may be found in Bedell and Crehore's "Alternating Currents" (Whittaker & Co., 1895), pp. 182–3 and 190–1.

determination of the values of a and β in general practice, which now becomes necessary.

As already stated, p is 2π times the number of complete cycles per second, which can theoretically be given any value whatever; the lower the value selected, the higher become the cost and weight of the transforming and generating plant, and the lower becomes their efficiency at light loads. The latter point is seldom important in long-distance transmission-schemes, as in such projects a cheap source of power is usually implied. A more important consideration than increased cost of the generating-plant, which after all only represents a small fraction of the cost of the line, is the fact that at very low frequencies the regulation of the generators becomes exceedingly bad. As an ordinary case, a frequency of 24 cycles per second may be taken, so that p is about 150.

The resistance per unit length of the line, r, depends on the material and cross-sectional area of the conductor. The increase in resistance due to the effect of self-induction internal to the wire (investigated by Lord Rayleigh and Lord Kelvin), which is large enough to demand attention in very heavy conductors at high frequencies, is negligible in long-distance transmissions, where low frequencies and comparatively small conductors must be used. If considered at all in these cases it should be regarded as a simple but very slight increase in resistance. In copper of ordinary sizes it will not amount to one-half of 1 per cent. It would be much increased if aluminium were used, but this is not likely to be the case in long-distance work owing to the important increase in the capacity-effects of the line which the necessity of using a wire of larger diameter would involve. A copper wire of, say, 0·425 inch in diameter has a resistance of 0·3 ohm per mile, giving for the resistance of a mile of a system of two wires 0·6 ohm.

There remain to be fixed the capacity and the self-induction for the unit of length. For cylindrical parallel wires these are easily calculated, as each depends on a simple integration. The results obtained are for the capacity per unit of length of two parallel cylindrical wires of radius a, and distance apart b.

$$c = \frac{1}{4 \log_e \frac{b}{a}} \quad \ldots \ldots \ldots \quad (13)$$

For the self-induction of the same two wires per unit of length the result is

$$l = 4 \log_e \frac{b}{a} + 1 \quad \ldots \ldots \ldots \quad (14)$$

It is noteworthy that both of these expressions are completely fixed when the ratio between the radius of, and the distance between, the wires is fixed, so that a proportionate increase or decrease of both the radius and the distance leaves the two results unaltered. Further, any change in this ratio which decreases the capacity increases the self-induction, and *vice versa;* also, as only the logarithm of the ratio appears, it is clear that an alteration of either the radius or the distance apart does not produce by any means a proportionate alteration in the capacity and self-induction. Consequently no very great variation is produced in these, even when the geometry of the system is very largely changed.

Of the two expressions (13) and (14), (13) gives the capacity in absolute electrostatic units, and (14) gives the self-induction in absolute electro-magnetic units. Taking the diameter of the wire, as before, at 0·425 inch, and the distance between the two wires as about 18 inches, c becomes, when converted to farads per mile, approximately

$$1 \times 10^{-8}.$$

and l similarly converted to henrys per mile becomes

$$3 \times 10^{-3}.$$

Since r, c, and l are determined in ohms, farads, and henrys, respectively, per mile of the system, x will be in miles, and v_x and i_x will give instantaneous values in volts and amperes respectively when V and I are the maximum values in volts and amperes respectively at the point of delivery.

Putting these values for p, r, c, and l in equations (11) and (12), the values found for α and β are

$$\alpha = \frac{4 \cdot 7}{10^4}$$

$$\beta = \frac{9 \cdot 5}{10^4}$$

α and β are thus very small quantities, and even for such values of x as 400 miles, αx and βx are proper fractions. Use may therefore be made of the expansions in powers of αx and βx for the expressions $\epsilon^{\alpha x}$, $\epsilon^{-\alpha x}$, $\sin \beta x$ and $\cos \beta x$. If these substitutions be made in the general equations (9) and (10) and special values be given to certain of the constants, a check may be obtained on the accuracy of the expressions. For instance, if c be given the value 0, which makes α and β also equal to 0, the two equations becomes

$$\begin{aligned} v_x = {} & \mathrm{V} \sin p t + p l \mathrm{I} x \cos (p t - \phi) \\ & + r \mathrm{I} x \sin (p t - \phi) \end{aligned}$$

$$i_x = \mathrm{I} \sin (p t - \phi)$$

which are the ordinary equations in the case of conductors considered to have resistance and self-induction only.

Again, if I is 0, the equation for i_x becomes

$$i_x = \frac{V\sqrt{cp}}{\sqrt[4]{r^2+p^2 l^2}} \cdot \sqrt{e^{2\alpha x} + e^{-2\alpha x} - 2\cos 2\beta x} . \sin(p t + \theta)$$

showing that the maximum value (or the virtual value, *i.e.*, the square root of the mean square if V is given as a virtual value) of the current that flows into the unloaded line is

$$\frac{V\sqrt{cp}}{\sqrt[4]{r^2+p^2 l^2}} \cdot \sqrt{e^{2\alpha x} + e^{-2\alpha x} - 2\cos 2\beta x}.$$

If both r and l are zero, a supposition which makes α and β also zero, this simplifies to

$$V c p x.$$

an expression commonly used for the charging-current of a line. From the foregoing reasoning, however, it is evident that it would only be strictly accurate if r and l were both zero, which, of course, is never the case, although the error introduced by neglecting higher powers of αx and βx is not in most cases large enough to be important.

By a common trigonometrical transformation the expression for v_x can be put into the form

$$v_x = \sqrt{L.V^2 + M.V.I. + N.I^2} . \sin(p t + \theta) . \quad . \quad (15)$$

where $L = \frac{1}{4}(e^{2\alpha x} + e^{-2\alpha x} + 2\cos 2\beta x)$

$$M = \frac{1}{2cp}\left\{\begin{matrix}(\beta\cos\phi - \alpha\sin\phi)(e^{2\alpha x} - e^{-2\alpha x}) \\ + 2(\alpha\cos\phi + \beta\sin\phi)(\sin 2\beta x)\end{matrix}\right\}$$

and $N = \frac{1}{4c^2p^2}(e^{2\alpha x} + e^{-2\alpha x} - 2\cos 2\beta x)(\alpha^2 + \beta^2)$

and θ is the angle of which the tangent is the fraction which has for numerator the coefficient of cos pt in equation (9) and for denominator the coefficient of sin pt in the same equation. These coefficients are very cumbrous in form, and need not be given here in full. θ then represents the angle by which the voltage at the point x leads that at the point O. The expression for i can be put into a corresponding form, and the tangent of the angle by which the amperes at the point x lead those at the point O can be similarly determined. The angle between the phases of the volts and the amperes at the point O being, by supposition, ϕ, the angle between the volts and the amperes at the point x can be determined.

So far as the direct effects of the line alone are concerned, the amount of regulation required in the voltage on account of a change in value of the current I will obviously depend on the magnitude of the coefficients M and N in equation (15), and the range of regulation is made small by making M and N small. By expanding the exponential and trigonometrical functions, the following approximate values are obtained:—

$$M = 2x(r\cos\phi + pl\sin\phi) \quad . \quad . \quad . \quad (16)$$

$$N = x^2(r^2 + p^2 l^2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

so that the condition that M and N are to be small entails primarily that r and pl, that is the resistance and the self-induction, shall be small; and these would be the conditions to be aimed at if a source of electric supply constant at the line voltage at all loads and angles of lag could be secured. In practice, however, this is not the case, as the capacity and self-induction of the line, by changing the angle of lag or lead as the load changes, have an indirect effect on the pressure-drop in the transformers and generators, which is of such magnitude as, in most cases, altogether to outweigh the direct effects. It becomes therefore of more importance to reduce the angle of lag or lead than to reduce the line-resistance.

As already explained, the angle between the phases of the volts and the amperes at the point x can be determined from the equation (15) for v_x and the corresponding equation for i_x. When the expression which is obtained for it, which in its original form is somewhat complicated, is simplified by expanding the logarithmic and trigonometrical functions and subsequently rejecting powers of αx and βx higher than the first, the approximate formula for the angle of lag that is obtained is

$$\phi + \tan^{-1}\left(\frac{plx\,I^2\cos\phi - rx\,I^2\sin\phi - cpx\,V^2}{rx\,I^2\cos\phi + plx\,I^2\sin\phi + V.I.}\right) \quad (18)$$

which may be reduced to

$$\tan^{-1}\left(\frac{plx\,I^2 - cpx\,V^2\cos\phi + V.I\sin\phi}{rx\,I^2 + V.I\cos\phi + cpx\,V^2\sin\phi}\right). \quad (19)$$

As this angle has to be kept small, its tangent

$$\frac{plx\,I^2 - cpx V^2\cos\phi + V.I.\sin\phi}{rx\,I^2 + V.I\cos\phi + cpx\,V^2\sin\phi} \quad (20)$$

has also to be kept as small as possible, whatever the variations in the current I may be.

In considering this expression, the point that first attracts

attention is that any reduction of r, the resistance of the line, does not improve the regulation at all, but actually serves to make it worse. Several other interesting deductions may be made when the ratio between the normal current and the normal voltage is known, especially when it is also kept in mind that the actual energy received is $\frac{V.I.}{2} \cos \phi$, where V and I are maximum values, or V.I. $\cos \phi$ when they are the square roots of the mean square values.

In general, it is clearly an advantage to make p small; c and l should also be diminished as much as possible, the reduction of the former being of more importance when I is small, and of the latter when I is comparatively large. Whenever I is large enough to make the numerator of the fraction positive it is advisable to reduce V.I $\sin \phi$ by making ϕ small; that is to say, the current received should if possible not be allowed to lag much when the load is heavy. On the other hand, when I is very small the terms $-cpx\mathrm{V}^2 \cos \phi$ and $cpx\mathrm{V}^2 \sin \phi$, in the numerator and denominator respectively, become of more importance than the others, so that under these circumstances the difference in phase between the volts and the amperes at the power-house (where the current now leads the voltage) can only be reduced by diminishing the ratio $\frac{\cos \phi}{\sin \phi}$; that is by making ϕ, the angle of lag at the receiving-station, large. This, as it happens, actually occurs when, as is usually the case in long-distance transmissions, step-down transformers are used at the receiving-station, for these, when not loaded, take a current that has a heavy lag.

The main requirements for good regulation, therefore, are ordinarily the following:—

1. High voltage, which, by reducing the load-current for a given power, minimizes both the indirect and direct effects of change of load; it, however, increases the indirect effects at light loads.

2. Low frequency, which reduces both the indirect and direct effects of change of load.

3. Small capacity, which reduces the indirect effects of change of load when the load is light, but does not do so when it is heavy.

4. Small self-induction, which reduces the direct effects of change of load at all loads, and the indirect effects when the load is large, but increases the indirect effects at very light loads.

5. Low resistance, which reduces the direct effects, but increases the indirect effects at all loads.

It will be seen that it is impossible to lay down very definitely any general rules that should be adhered to in all cases, as so much depends on the magnitude and nature of the loads to be expected. All that can be done is to investigate the various effects in any specific case, and then select the arrangement that is best suited on the whole to the particular conditions. The extent to which variations of some of the quantities involved can be carried has already been referred to in ascribing to them practical values for the purpose of investigating the general equations (9) and (10). It was then mentioned that the limit to the reduction of the frequency was brought about by the difficulty of designing good generators to work at very low frequencies. The connection between the values of the capacity and self-induction of an overhead line was given, and it was pointed out that an increase in the one caused a decrease in the other, and *vice versa*; also, that no very great alteration in either is possible when the distance between the wires is limited in practice by the necessity of carrying them on one line of poles. In connection with this point the effect of using duplicate lines in parallel is worth considering. This is an arrangement that is usually proposed in order that a breakdown on the line shall not necessarily entail a stoppage of power-supply during the time when repairs are being carried on. Its adoption has an important bearing on the financial side of any transmission-scheme, as it still further increases the cost of that portion of the line which is practically independent of the weight of copper used. Even on a single line this cost often, especially in climates where iron poles have to be used, exceeds the cost of the copper, so that it is very evident that the capital expended on a line cannot even approximately be considered as the cost of the wire on it. Thus, doubling the line makes the current in each portion half its original value; the resistance of each portion is twice the original value, whilst the self-induction and the capacity are only altered to a very slight extent. The result is to reduce the direct line-effects at all loads. The indirect effects may be either reduced or increased according to the ratio that the original current bears to the voltage. At light loads, when the current leads, the lead is increased by halving the current, and regulation is worse. At heavy loads, when the current lags, the lag is decreased and regulation is improved. On the whole, taking both direct and indirect effects into consideration, the usual result is an improvement in regulation from doubling the line.

The limits to the voltage that may be adopted have not yet

been referred to. The first difficulties that are met with in increasing the voltage are usually in connection with the insulators. As has been pointed out by the Author,[1] the use of high voltages necessitates large insulators, and the only materials that are electrically satisfactory—porcelain and glass—give trouble through mechanical weakness when they are made in pieces of large size. Already, however, insulators are procurable that will withstand 60,000 volts, and there appears to be no reason why a certain amount of further improvement should not be attainable if necessary It is unlikely, however, that any great advance in this respect will ever be called for, owing to the probability of a more serious difficulty imposing a maximum limit to the voltage that may be employed. This difficulty lies in the continuous brush-discharge that occurs from wire to wire with very high voltages. In experiments in statical electricity it is found that when the surface-density of the charge on a conductor reaches 20 electrostatic units per square centimetre a brush-discharge in dry air is always maintained. The voltage between two wires of course produces a surface-density of charge, the value of which depends on the capacity between them and also on the extent of their surface, the formula connecting the two being

$$V = 2{,}400\,\pi\,\rho\,a \log_e \frac{b}{a}.$$

where V denotes the voltage, ρ the surface-density, a the radius of each wire and b the distance between the two wires. With wires of 0·425 inch diameter at a distance of 18 inches apart this critical value would be reached at a pressure of about 110,000 volts. This pressure is attained at the crest of the wave of an alternating voltage of about 80,000 volts, assuming that the sine law is obeyed.

Consequently it would appear that for wires of this size and distance apart, a voltage of 80,000 volts is a limit which it will never be possible to exceed. Some interesting experiments showing the amount of power consumed by these brush-discharges have been carried out at Telluride, Colorado, by Mr. Mershore.

The Paper is accompanied by a diagram from which the figure in the text has been prepared.

[1] "Electric Transmission Plants at Moodie's, De Kaap Goldfields, Transvaal." Minutes of Proceedings Inst. C.E., vol. cxli. p. 269.

OBITUARY.

JOHN HICKMAN BARNES, born on the 16th February, 1837, obtained his engineering training under the late Mr. James Meadows Rendel, Past-President, and subsequently under the late Mr. Nathaniel Beardmore. He was then engaged for three years on the Petworth and Midhurst and the Horsham and Guildford railways, after which he acted from 1864 to 1871 as Principal Assistant to Mr. Beardmore, being occupied during that period in inspecting harbour and dock works, waterworks and railways, in drawing up reports to the Public Works Loan Commissioners, and on works connected with the River Lee Navigation and with the maintenance of the Thames River Wall under the jurisdiction of the Essex Sewers Commissioners.

In January, 1872, Mr. Barnes was taken into partnership by Mr. Beardmore, and, after the latter's death in the following August, he carried on the business of the firm in conjunction with the late Mr. St. Bernard Beardmore, the eldest son. In September, 1872, he was appointed Engineer to the Havering and Dagenham Levels Commissioners, in succession to Mr. Beardmore, and in the following December, he and Mr. St. Bernard Beardmore were placed in charge of the construction of a large storage reservoir for the water-supply of Llanelly. In 1885 he became Engineer to the Rainham Levels Commissioners.

Mr. Barnes also acted as Engineer on the construction of the Carmarthen and the Maritzburg (Natal) Waterworks and of the Penzance Docks. For the Public Works Loan Board he reported on and, in some cases, carried out, between 1881 and 1903, a considerable amount of work in connection with various harbours, among which may be mentioned St. Ives, Falmouth, Bridlington, Warkworth, Mevagissey, Portrush, Stonehaven and Watchet. He was also engaged at various times on work for the Lee Conservancy Board, the New River Company and the East London Water Company. Mr. Barnes died at Manor Lodge, Egham, on the 30th October, 1903, in his sixty-seventh year.

He was elected an Associate of the Institution on the 7th February, 1865, and was transferred to the class of Members on the 29th May, 1877.

HENRY MARC BRUNEL—second son of Isambard Kingdom Brunel and grandson of Sir Marc Isambard Brunel—who died at his residence, 21 Abingdon Street, Westminster, on the 7th October, 1903, in the sixty-second year of his age, was the last male representative of that illustrious family, and with his death ceased also its long connection with this Institution, of which his father was a Vice-President and his grandfather was elected a Member in 1823.

The subject of this notice, although only 17 when his father died in 1859, had taken part in some of the later engineering works with which Isambard Kingdom Brunel was associated, notably in the launch of the well-known steamship "Great Eastern;" and the details he subsequently contributed to the "Life of I. K. Brunel," published in 1870, in the compilation of which he was engaged for some years in conjunction with his elder brother, the late Dr. Isambard Brunel, Chancellor of the Diocese of Ely, were furnished in some measure from personal experience and recollection.

Born in 1842, Henry Brunel, after being educated at Harrow and at King's College, London, was apprenticed in 1861 for three years to the firm of Sir William Armstrong and Company at Elswick. He subsequently served a pupilage to Mr. (afterwards Sir John) Hawkshaw, Past-President, with whom he remained as an Assistant until 1870. During the period of his connection with Sir John Hawkshaw he was engaged on the construction of Penarth Dock, near Cardiff, and of the Albert Dock at Hull, and also in an elaborate examination into the condition of the Caledonian Railway system, and in an important series of soundings in the English Channel, undertaken with a view to the selection of the best route for the Channel tunnel proposed by Sir John Hawkshaw.

Between 1870 and 1878 the subject of this notice was closely associated with the late Mr. William Froude, F.R.S., formerly a member of his father's engineering staff, and well known in connection with scientific researches bearing on naval architecture. In these researches and in the experiments on the resistance of ships, and on the cognate subject of their propulsion, carried out by Mr. Froude for the Government in the Admiralty establishment at Torquay, Henry Brunel took keen interest, placing his services unreservedly at the disposal of Mr. Froude. During that period he was also engaged on the construction of a large reservoir for the water-supply of Torquay and on a comprehensive

investigation of methods for the prevention of waste. In 1874 he visited Brazil in order to examine and report on the large public hydraulic hoists for passengers between the lower and upper towns at Bahia, and was also occupied in connection with a variety of parliamentary proposals.

In 1878 Henry Brunel entered into partnership with Mr. (now Sir John) Wolfe Barry, Past-President, to whom he was united to the day of his death by the closest and most intimate ties of friendship, and his subsequent professional career was bound up with that of Sir John. Among the various works with which he was thus intimately connected may be mentioned the important Barry Dock in South Wales, Blackfriars railway bridge over the Thames and St. Paul's Station, The Tower Bridge and the bridge recently erected at Connel Ferry, near Oban, for the extension to Ballachulish of the Callander and Oban Railway. Bearing in mind the substitution of machinery for manual labour in the making of ships' blocks, introduced by his grandfather in 1806, the construction of the Thames Tunnel carried out by his grandfather and father in the face of difficulties of the most serious nature, and Hungerford Suspension Bridge, now spanning the Avon at Clifton, the Great Western Railway, and the steamships "Great Western," "Great Britain" and "Great Eastern," designed by his father, it may well be said that the name of Brunel will ever remain peculiarly associated with the progress of engineering during the nineteenth century.

Henry Brunel's personal character endeared him deeply to all his friends. His keen and singularly whimsical humour, which, with some reserve of manner with strangers, at first sight perhaps seemed his chief characteristic, was thrown into the shade for his intimates by his rigid principle, high purpose, sympathy and warmth of heart. In the autumn of 1901 he had a slight apoplectic stroke, resulting from the bursting of a blood-vessel in the brain, from the effects of which he never fully recovered. He was a Member of the Institution of Mechanical Engineers and of the Institution of Naval Architects.

He was elected a Member of this Institution on the 6th March, 1877, and was for many years a frequent attendant at its meetings.

THOMAS RHODES FIRTH was born in Yorkshire in May 1832. His professional career commenced in 1848, when he was articled to a relative, Mr. Thomas Rhodes, Civil Engineer, who at that time had an extensive practice. On completion of his pupilage he received an appointment from Messrs. Peto, Brassey and Betts, and assisted in the construction of some railways in France. The firm taking up contracts in Australia, Mr. Firth was appointed one of their engineers, and, with other members of their staff, arrived in New South Wales in 1859. In the following year the extensions from Parramatta to Penrith on the west, and to Menangle and Picton on the south, were started, and in 1862 the extension of the Northern line to Branxton and Singleton was commenced. While acting for the contractors on those works he had attracted the attention of the late Mr. John Whitton, the Government Engineer-in-Chief, who, in 1862, offered Mr. Firth the appointment of District Engineer. This offer he accepted and thus commenced his long connection with the Railway Construction Branch of New South Wales.

Tempted by an offer of high salary he resigned his appointment in 1878 to join a contracting firm, but after a short experience found the work unsatisfactory and returned to the Government service, taking up his former position as District Engineer in charge of various contracts, principally on the Southern line. In 1889 he had control of the trial surveys, and in that position had much to do with the location of various lines. In the following year he was promoted to Chief Assistant Engineer for Railway Construction, which position he held until 1895, when he was transferred to the service of the Railway Commissioners as Engineer-in-Chief for Existing Lines. In that capacity he was responsible for the maintenance of all the Government railways in New South Wales, involving the carrying out of many important works, such as duplication of lines, improvement of grades and curves, renewals of bridges, besides the innumerable matters which claim the constant attention of the Maintenance Engineer of a large system.

Early in 1902 Mr. Firth's health showed signs of weakness, and extended leave was granted him until March, 1903, when, no improvement having taken place, he retired from the Government service. He died on the 20th July, 1903, from Bright's disease.

Mr. Firth was elected a Member of the Institution on the 5th December, 1876.

SAMSON FOX, born on the 11th July, 1838, at Bradford, Yorkshire, went to work at about ten years of age at a cloth mill in Leeds, where his father was also employed. Showing an early aptitude for mechanics, he was afterwards apprenticed to the firm of Smith, Beacock and Tannett, machine-tool makers, Round Foundry, Leeds, where he became foreman and ultimately traveller. Whilst in the employ of Smith, Beacock and Tannett he designed several special tools for the machine cutting of bevelled gear and for the manufacture of trenails, and for several of those machines he took out patents. In 1862 he was in charge of the machine-tool exhibit of Smith, Beacock and Tannett at the London Exhibition. Later he started a small engineering works in Leeds —the Silver Cross Works—for the manufacture of special machine-tools.

In 1874 Mr. Fox founded the Leeds Forge Company for the manufacture of iron, boiler plates, and general forging works. In 1877 he took out his first patents for the manufacture of the Fox corrugated boiler furnaces, the material for which originally was best Yorkshire iron, the corrugations of the furnaces being hammered by means of swage blocks under a steam-hammer. The advantages of the Fox corrugated furnaces led to the practical application of triple expansion engines, machinery for rolling the furnaces in place of hammering them was undertaken in 1882, and a Siemens steel plant was laid down for manufacturing the material for plates for the production of the furnaces. From 1877 Mr. Fox took out a large number of patents for various details connected with the manufacture of corrugated furnaces.

In 1887 and 1888 he took out patents for the manufacture of pressed steel underframes for railway wagons, etc. The works of the Leeds Forge Company were further extended in 1889 for the manufacture of this new form of railway rolling stock. In 1888 Mr. Fox started works for the manufacture of steel frame rolling stock at Joliet, near Chicago, and made there the first pressed steel cars used in America, and large numbers of the Fox pressed steel bogie truck, which was principally used for freight cars and met with great success. The extension of the business in America led to works being built at Pittsburg, and these were merged in 1899 into the Pressed Steel Car Company. He was also identified with extensive experiments in connection with water-gas.

Mr. Fox was the greater part of his business life at Leeds the Managing Director of the Leeds Forge Company, and had

succeeded to the Chairmanship of the Company just before his death, which took place at Walsall on the 24th October, 1903.

Mr. Fox was a member of the Corporation of Leeds for several years and three years in succession Mayor of Harrogate, where he resided. He was a life governor of the Yorkshire College and Justice of the Peace for Leeds and Harrogate. A great lover of music, he made through the King (then Prince of Wales) a munificent gift to the Royal College of Music at South Kensington. He was a member of the Legion of Honour of France.

Mr. Fox was elected a Member of the Institution on the 5th April, 1881.

JAMES MORRIS GALE,[1] who, for a period of fully forty years, was the Engineer-in-Chief to the Glasgow Water Commissioners, died on the 7th September, 1903, at his residence at Aberfoyle, which lies in the district of the famous Loch Katrine water scheme, by which his name will be known to future generations of water engineers. He retired from his post at the end of 1902, with the respect and esteem of his employers—the Water Commissioners. Before his retirement took place he had been relieved from active duty on account of general weakness; but his work was so thoroughly organized that his department went on without making great demands on him. Had he been less anxious about it, probably his life might have been extended considerably.

Mr. Gale was a native of Ayr, where he was born in the year 1830. After receiving his education at the academy there, he joined the engineering staff of his elder brother, William Gale, who constructed the works of the Gorbals Gravitation Water Company, the gathering ground of which lies from seven to ten miles on the south side of Glasgow. While thus employed with his brother, Mr. Gale attended the engineering classes of Professor W. J. Macquorn Rankine in the University of Glasgow, and the mathematical classes of Professor Laing in Anderson's College. Later, for eight years he occupied the position of Assistant Engineer to his brother, and in the year 1855, when the great Loch Katrine scheme was put into operation under Mr. J. F. La Trobe Bateman, Past-President, who was then one of the leading water engineers in the kingdom, Mr. Gale was appointed Resident Engineer on the city section of the works which depended on

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[1] This notice, with some modification, has been reprinted from *Engineering*, 11 September, 1903, by permission of the Editors.

Loch Katrine as the source of supply. Mr. Gale continued with the Glasgow Water Commissioners until the works were finished and handed over to the corporation, and he was appointed at the close to the post of Chief Engineer to the Commissioners. He subsequently read a Paper on the Glasgow water works before the Institution of Engineers and Shipbuilders in Scotland.[1]

But although the scheme of works was intended to supply to Glasgow and its suburbs a quantity of water amounting to 50,000,000 gallons per day, it was found by the year 1882 that a fresh supply of water would soon be required, and under Mr. Gale's advice and guidance it was resolved by the Corporation Water Commissioners to apply to Parliament for powers to construct another aqueduct, calculated to carry from Loch Katrine[2] an equal amount of water. Mr. Gale's scheme for doubling the supply was carried through both Houses of Parliament, and was at once put into execution. It especially included the raising of the boundaries of the loch, and it brought into assistance and use other lochs in the Loch Katrine area. The scheme was carried out exclusively by Mr. Gale and his staff, and it is a splendid piece of work.

Mr. Gale served the office of President of the Institution of Engineers in Scotland in 1867-68 and 1868-69. The addresses he delivered from the chair dealt with the engineering works carried out in the preceding ten years, and with the works which might be expected to be undertaken in the succeeding ten years, especially by the City of Glasgow. He read a number of Papers before that Institution, one of which was a description of the water works that were constructed for Port Glasgow. That Paper was deemed so important that Mr. Humber selected it as one dealing with a typical works, and published it in 1876 in his volume on "The Water Supply of Cities and Towns." In his later years he seldom attended the meetings, owing to failing health; but he acted faithfully for a number of years as the treasurer to the Institution.

One feature of Mr. Gale's character was his industry and his methodical treatment of affairs. He early adopted the Deacon waste-water meter, of which he ultimately had no fewer than eighty installed and in use, controlling the water supply in districts of Glasgow where there were about 160,000 inhabitants. He was

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[1] Transactions of the Institution of Engineers and Shipbuilders in Scotland, vol. vii. p. 21.

[2] See *Engineering*, vol. lvii. pp. 469, 535, 601, 635, 703 and 738.

selected as a member of a Commission—his colleagues being Messrs. Hill and Mansergh—on the Edinburgh Water Works.

Mr. Gale was elected a Member of the Institution on the 2nd February, 1864. In the year 1888-89 he filled the office of first President of the reconstituted Glasgow Association of Students of the Institution.

WILLIAM JOSEPH KINGSBURY,[1] youngest son of the late Mr. Thomas Kingsbury, formerly of The Priory, Bathwick Hall, Bath, was born at Clapton, Middlesex, on the 30th December, 1825. He was educated at private schools, and entered at about the age of 15 the College for Civil Engineers at Putney, where he took the first place in mathematics every year, and obtained its diploma in 1849.

On leaving Putney College he was offered the position of assistant to Professor John Wilson, who was carrying on boiler experiments in connection with coals suited for the steam Navy, and the results were embodied in the first Report issued by the Commissioners, Sir H. De la Beche and Dr. Lyon Playfair Mr. Kingsbury returned home, after a short period of employment under Mr. Charles Liddell, owing to his father's serious illness, but in August, 1852, he received an introduction to Mr. George Parker Bidder, Past-President, and this proved to be the starting-point of his professional career and of an association of friendship unbroken until Mr. Bidder's death in 1878.

Mr. Bidder placed him with Mr. John Mortimer Heppel, then occupied with preliminary calculations and sketches for the large wrought-iron gates for the Victoria Docks, and in the preparation of contract drawings for the Hackney branch of the Eastern Counties Railway (now part of the Great Eastern system). On Mr. Heppel's leaving England for an appointment in Switzerland at the end of 1852, Mr. Kingsbury came into Mr. Bidder's office, and was placed in charge of details of lock-gates and caissons, subsequently becoming Resident Engineer under Messrs. Bidder and Berkley of the Woodford and Loughton branch of the Eastern Counties Railway in 1855. At the end of 1856, on the retirement of Mr. W. P. Gale, Mr. Bidder offered him the post of Private Secretary, and placed him in charge of the office. In 1859 he presented to the Institution, at Mr. Bidder's request, a

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[1] This notice is mainly autobiographical.—Sec. Inst. C.E.

Paper entitled "Description of the Entrance, Entrance Lock, and Jetty-Walls of the Victoria (London) Docks; with a detailed account of the Wrought-Iron Gates and Caisson, and remarks upon the form adopted in their construction,"[1] for which he was awarded a Telford Medal and a Manby Premium.

In 1857–59, Mr. Bidder being associated with Mr. Joseph Jennings as Engineers for new entrance and gates to the Grand Surrey Docks, Mr. Kingsbury acted as Resident Engineer, and in subsequent extensions as joint Engineer with Mr. Jennings, Mr. Bidder being Consulting Engineer. Subsequently the Graving Dock at Lowestoft, working up tidal observations along the Llanelly shore, the Bow and Barking Branch of the London, Tilbury and Southend Railway, for which he prepared the bridge designs, and numerous important arbitrations claimed his attention.

In 1862 Mr. Bidder became Consulting Engineer of the Scinde Railway Company and of three other closely connected companies, and this opened up an enormous amount of work, especially in connection with the testing of material on a wider basis than had been previously practised by engineers. The most important event in 1865 was the making of the Delhi contract of 304 miles from Lahore to Delhi with Messrs. Brassey, Wythes and Henfrey—the largest contract, it is believed, ever carried out in India—and the specification demanded and received special attention. The bridge designs were prepared by the late Mr. John Harrison Stanton, and the remainder of the work by Mr. Kingsbury. The line was completed in 1871. The Indus Valley Company commenced a railway survey for a line between Kotri and Multan, but this was stopped by Government in 1866, and at about this date the four undertakings were amalgamated as the Scinde, Punjaub and Delhi Railway.

In 1865 the Kemp Town extension of the Brighton and South Coast Railway was made, of which Mr. Kingsbury was Resident Engineer, and other branches of the Brighton Company also received his attention.

In 1866 Mr. Kingsbury made interesting experiments in vibration, under Mr. Bidder's directions, along the Marylebone Road before writing his Report to the Dean and Chapter of Westminster on the risk of danger to Westminster Abbey from the proposed District Railway. In 1874 Mr. Bidder became interested in the Swindon, Marlborough and Andover Railway, and the construction of the line was carried out with Mr.

[1] Minutes of Proceedings Inst. C.E., vol. xviii. p. 445.

Kingsbury and Mr. Shopland as Engineers, and Mr. Bidder as Consulting Engineer. On the death of Mr. Bidder in 1878 the Scinde, Punjaub and Delhi Railway Company appointed Mr. Kingsbury his successor as Consulting Engineer, and he held the appointment until the contract between the Company and the Indian Office lapsed about 1886, when Mr. Kingsbury relinquished practice.

Mr. Kingsbury was for a few years a Director of Prentice's Gun Cotton Works at Stowmarket and made many experiments in coal mines, slate quarries, etc. He was also a Director, for over thirty years, of the Danish Gas Company and took a keen interest in its affairs. Mr. Kingsbury's great recreation through life was music, and for many years he conducted choral meetings in his own house and gave concerts for charitable purposes. He died at his residence, 64 Burton Court, Lower Sloane Street, S.W., on the 9th January, 1904.

Mr. Kingsbury was elected an Associate of the Institution on the 2nd February, 1858, and was transferred to the class of Members on the 8th December, 1863.

THOMAS PARKER, who died at his residence, Gorton House, Gorton, Manchester, on the 25th November, 1903, was born in Ayrshire in 1829. In 1847, after some practical experience, he entered the Locomotive Department of the Caledonian Railway Company at Greenock, under Mr. Robert Sinclair, and, with the exception of two years, 1851–53, during which time he was engaged in the Locomotive Departments of the London and South Western and the Scottish Central Railways, he remained in the service of the Caledonian Company until 1858, when he was appointed Carriage and Wagon Superintendent of the Manchester, Sheffield and Lincolnshire Railway. On the resignation of Mr. Sacré in 1886 he succeeded to the post of Locomotive Engineer to the Company. During his long connection with the Manchester, Sheffield and Lincolnshire Railway he erected the present carriage and wagon shops; he was one of the first to construct 6-wheeled bogie coaches, and the dining-car built by him in 1885 was one of the first in the country. He designed for the Manchester Jubilee Exhibition Engine No. 561, which was one of an entirely new type on the line, and he was one of the first to use Belpaire fire-boxes extensively in this country. In 1892 he remodelled the locomotive shops and built the large new erecting shop. He was

called in to inspect the rolling stock of the Metropolitan Railway Company and of the Cambrian Railway Company. Mr. Parker retired in 1893 after a career of nearly fifty years.

He was elected a Member of the Institution on the 8th January, 1889.

JOHN PENN, M.P., died at his residence, 22 Carlton House Terrace, on the 21st November, 1903, at the comparatively early age of 55. The eldest son of the late Mr. John Penn, F.R.S., he was born at Lewisham on the 30th March, 1848, and, after being educated at Harrow and at Trinity College, Cambridge, assisted at an early age in the management of the firm of John Penn and Sons, marine engineers, of Greenwich and Deptford; and when, later, the business was converted into a limited company, he assumed its chairmanship.

Soon after joining the firm Mr. Penn turned his attention to an arrangement of 3-cylinder expansive vertical engines, the three cylinders being of the same size and worked expansively at 60 lbs. pressure for full power, and for half-power worked compound (*i.e.*, high pressure in one cylinder only, the steam exhausting into the other two) by an arrangement of stop valves. These engines were put forward as good for manœuvring purposes, and were found to be able to run evenly at a very low number of revolutions per minute. This type was fitted in the "Northampton," "Ajax" and "Agamemnon" in the British Navy, and in several vessels of the Italian Navy, notably the "Christoforo Colombo," the "Italia" and the "Lepanto."

In 1893–95 Mr. Penn was much interested in the question of induced as compared with forced draught for increasing the evaporative performance of boilers. He was of opinion that, in addition to the advantage of open stokeholds, there would be less risk of damage to the boiler under induced draught, and that there would always remain a better chance of maintaining a high power in the engines in the event of the funnels of a war-ship being shot away. Such apparatus was fitted to the boilers of H.M.S. "Magnificent" and "Illustrious," twin-screw battle-ships with triple expansion engines of 12,000 HP. and 150 lbs. working pressure, which passed through successful trials.

The introduction of water-tube boilers and 300-lbs. steam-pressure caused a revolution in design, and with the exception of the machinery for the cruisers "Pactolus" and "Pomona," and for

the battle-ship "Goliath," Mr. Penn had had but little to do with vessels of this type when he retired from business in 1899.

Mr. Penn was M.P. for Lewisham from 1891, and his experience of marine engineering gave weight to his opinion on naval matters in the House. The high tone of his business relations and his constant regard for the reputation of the name he inherited were always recognized. He was kind and generous, and enjoyed the high esteem of those in his employment at Greenwich. He was a Director of the Kent Waterworks and of the Great Eastern Railway Company. In his leisure moments he was a keen cricketer, a good shot and an enthusiastic golfer, in which last capacity he was always to be found in the various Parliamentary handicaps.

Mr. Penn was elected an Associate of the Institution on the 3rd February, 1874, was subsequently placed among the Associate Members, and was transferred to the class of Members on the 27th January, 1880.

THOMAS FORTH ROTHERAM, Chief Mechanical Engineer to the Western Australian Government Railways Department, died suddenly, from *angina pectoris*, at his residence, Mount Street, Perth, Western Australia on the 11th September, 1903.

Born in England, at York, on the 28th June, 1850, he obtained his early engineering training in the Manchester, Sheffield and Lincolnshire Railway works at Gorton, and subsequently in the shops of the North British Railway at Cowlairs, Glasgow. With the approval of the officials of the latter line he afterwards took a position with the London and Glasgow Shipbuilding Company, for the purpose of gaining experience in the fitting and completion of the engines and boilers of large ocean steamers. He then returned to the North British Railway, and was appointed to take charge of the erection of indoor and outdoor machinery and plant. Subsequently he was engaged for three years with Messrs. Ransomes and Rapier, in the design and manufacture of fixed plant for railways in various parts of the world.

Early in 1875 Mr. Rotheram entered the service of the New Zealand Government Railways, in which Department he occupied the following positions:—General Manager of the Picton and Blenheim Railway (1875–78); General Manager of the Wanganui, Foxton and New Plymouth Railway (1878–85); Locomotive

Superintendent of the Hurunui-Bluff Railway (1885–88); and Locomotive Superintendent of the New Zealand Railways from 1888 to April, 1900, when he accepted the appointment of Chief Mechanical Engineer to the Western Australian Railways. While in the service of the New Zealand Government he introduced the complete manufacture in the railway workshops of many locomotives and other rolling-stock required. In 1887, while still connected with the New Zealand railway service, he was specially appointed by the New South Wales Government to report on the railways and tramways of that colony. In 1891 he was appointed by the New South Wales Railway Commissioners to inquire into the merits of the Westinghouse and vacuum brakes as applied to goods trains. In 1893, under instructions from the New Zealand Railway Commissioners, he visited America and Europe to make a personal examination of the working of compound locomotives, and to inquire into the feasibility of placing electric motors on a portion of the New Zealand Railways, and generally into questions affecting electric welding, locomotives, machinery and lighting.

Mr. Rotheram was elected a Member of the Institution on the 12th January, 1886.

ARTHUR SHANKS, born on the 22nd February, 1836, began his engineering career as an apprentice in the works of Messrs. Robert Stephenson and Company, of Newcastle-on-Tyne, with which firm he subsequently remained as an Assistant until 1861. Early in the following year he went to Calcutta, where he was engaged for some months in the Engineer's office of the River Steamer Company, and in November of that year he entered the service of the Eastern Bengal Railway Company as Assistant to the Locomotive Superintendent. In May, 1864, he was appointed Resident Engineer and Locomotive Superintendent of the Calcutta and South Eastern Railway, which post he held until June, 1868, when he resigned in order to become a member of the firm of Messrs. Burn and Company, of Calcutta and Howrah.

During the twenty-two years of his connection with Messrs. Burn and Company, Mr. Shanks was principally engaged in managing the Howrah Ironworks of that firm, in which capacity he was responsible for the construction of bridgework, roofing, lock-gates, engines, boilers, rolling-stock, and foundry work of all kinds. Retiring in 1890, he returned to England, where he died, at Heath

Place, Cowden, Kent, on the 17th August, 1903, in his sixty-eighth year.

Mr. Shanks was elected an Associate of the Institution on the 14th May, 1872, was subsequently placed among the Associate Members, and was transferred to the class of Members on the 11th March, 1884.

JOHN ALLSOPP, born on the 2nd August, 1848, served an apprenticeship to Messrs. Strutts, engineers and millwrights, of Milford, near Derby. From 1869 to 1872 he was employed by Messrs. Benton and Woodiwiss, contractors, in charge of important works on the Settle and Carlisle Railway and on the Duffield and Selston branch of the Midland Railway. He was then engaged for four years on drainage and sewerage work, and in 1876 he was appointed Engineer and Surveyor to the Local Board of Health of Worksop, in which capacity he carried out the present sewerage system of that town. In 1884 he resigned that post and devoted himself to private practice as an architect and surveyor. Mr. Allsopp was the first Engineer to the Worksop Waterworks Company. He was kind and generous in disposition, and in his younger days a great athlete. He died at Worksop on the 2nd November, 1903, at the age of 55.

Mr. Allsopp was elected an Associate Member of the Institution on the 6th April, 1880.

HERBERT HENDERSON, son of Mr. Joseph Henderson, Mining Engineer, of Liverpool and North Wales, was born on the 27th May, 1856, at Newport, Monmouthshire. He was educated at the Kirkcudbrightshire Academy, and commenced an engineering apprenticeship with Messrs. McKinnel, of Dumfries, completing it at the Vauxhall Foundry, Liverpool. In 1877 he was appointed Assistant to Mr. D. M. F. Gaskin, then Water Engineer of St. Helen's, Lancashire, with whom he was engaged in the preparation of the plans and part supervision of the Sutton Road Pumping-Station and the Brown Edge reservoir, and part supervision of the machinery at the various pumping-stations. He was also engaged in the experimental work for the softening of the Collins Green water, and in all this work he showed himself a careful, accurate and efficient assistant. With the object of extending his experience

of the details of waterworks and hydraulic appliances, he entered in 1879 the service of the Glenfield Company and the Kennedy Meter Company, since amalgamated as Messrs. Glenfield and Kennedy, and remained in their service until his death.

He contributed to the Proceedings of the Institution a Paper on "The removal of Corrosion from Water Mains,"[1] and also superintended with great success the clearing of the mains of several towns. He had a large circle of friends amongst waterworks engineers, by whom he was highly appreciated for his technical knowledge and for his bright genial temperament. He died after a few hours' illness at Belfast on the 9th July 1903, from a chill caught whilst on duty.

Mr. Henderson was elected an Associate Member of the Institution on the 23rd May, 1882.

ALEXANDER WILLIAM MOORE died from pneumonia at his residence, 32 Clanricarde Gardens, Bayswater, on the 17th April, 1903. Born at Sheerness in 1849, he was educated at King's College, London, and served his time as a pupil, first to Mr. John Wright, Locomotive Superintendent of the South Devon Railway, and subsequently to Mr. Henry Voss, Divisional Engineer of the Great Western Railway at Oxford. In 1872 Mr. Moore was appointed an Assistant on the Great Western Company's engineering staff. After some little time he was transferred to Paddington and attached to the staff of Mr. Lancaster Owen, Constructive Engineer to the Company, and was engaged in the preparation of the plans for the widening of the main line between Paddington and Slough. His other important work at Paddington was the laying out of Paddington Yard in connection with the abolition of the existing Hammersmith and City level crossing at Royal Oak, and constructing a subway in place of the crossing. On the completion of this work he was given charge of the Parliamentary Department of the Company, which position he occupied with great success for some years.

In October, 1883, Mr. Moore took up his residence in Frome as Engineer to that part of the Great Western Railway extending from Chippenham to Weymouth and Portland, and from Holt to Newbury. In July, 1893, he was appointed Divisional Engineer at Bristol, his division extending from Didcot to Portishead Junc-

[1] Minutes of Proceedings Inst. C.E., vol. cxvi. p 307.

tion, Swindon to Gloucester, Newbury to Bristol, and branch lines in connection.

In November, 1896, he was appointed to the important post of Administrative Assistant in the Chief Engineer's Offices at Paddington, where his duties were the conduct of the engineering business at head quarters. Mr. Moore's record had marked him out for a post where tact and firmness, coupled with the power of dealing with many and varied subjects, were required, and his tenure of this post showed that he was not found wanting in those qualities; indeed, the fact of there being such widespread and general regret at his untimely death unquestionably shows the skill with which he carried out the complicated duties the Great Western Railway Company called on him to perform.

Mr. Moore was elected an Associate of the Institution on the 7th March, 1876, and was subsequently placed in the class of Associate Members.

JAMES SCOTT, son of the late Mr. Thomas Scott, was born on the 20th October, 1846, at Keighley, Yorkshire. He served a pupilage to his father from 1862 to 1866, being engaged during that time on the construction of a portion of the Metropolitan Railway between Euston and Paddington, and of the Marple, New Mills and Hayfield line of the Manchester, Sheffield and Lincolnshire Railway Company. From 1866 to 1868 he was employed as Contractor's Engineer on Contract No. 1 of the Midland Railway's London Extension from the North London Railway, Kentish Town, to St. Pancras Goods-Yard. From 1868 to 1873 he was Contractor's Engineer on Contract No. 1 of the Settle and Carlisle Railway, and from 1873 to 1878 he occupied a similar position on the widening of the London and North-Western Railway's main line, from King's Langley to Bletchley, and from Clydach to Bryn Mawr. He was then employed from 1878 to 1883 on the Weymouth and Abbotsbury Railway, the widening of the Cheshire lines at Liverpool, and the River Witham Outfall Works at Boston; from 1883 to 1888, on the Baltinglass Extension of the Great Southern and Western Railway of Ireland, and on the Ripley and Heanor Extension of the Midland Railway, and the Nottingham Suburban Railway. From 1888 to 1895 he was employed as Contractor's Agent in superintending the construction of the Dore and Chinley Railway, Contract No. 2. The principal work on that section was the Cowburn Tunnel, nearly 4,000 yards in length, which, passing

under Cowburn Hill, 800 feet above the tunnel, had to be worked from two faces and without shafts, by driving a bottom heading right through.

From 1895 to 1899 Mr. Scott was the Contractor's Chief Agent on the Great Central Railway Extension to London, Contract No. 4, from Rugby to Woodford, on which the Catesby Tunnel, 3,000 yards in length, was constructed in the short period of two years and two weeks. Since 1899 he was engaged in a similar capacity on the Thackley Tunnel and widening of the main line, for the Midland Railway Company, on the Great Central contract from Neasden to Northolt, and on the widening of the Midland Railway from Finchley Road to Welsh Harp. Mr. Scott died on the 27th November, 1903. He was a most able Contractors' Agent, and carried out successfully some difficult and important undertakings.

He was elected an Associate Member of the Institution on the 1st May, 1894.

CHARLES TAYLOR, born on the 6th January, 1836, entered the service of the Nottingham Gas Company in 1850. Five years later he became Superintendent of that Company's station at Basford, and from 1861 to 1864 he occupied a similar position at the principal station at Nottingham. In 1864 he was appointed Engineer to the Derby Gas Company, which post he held until April, 1900. He also acted for a time as Engineer to the Long Eaton Gas Company and to the Castle Donington Gas Company, and occasionally as Consulting Engineer to the Ashby-de-la-Zouch and other Companies. During Mr. Taylor's tenure of the post of Gas Engineer at Derby the quantity of gas manufactured yearly increased from one hundred million cubic feet to five hundred and fifty million cubic feet, and branch works were established at Litchurch. Mr. Taylor was a member of the Derby Board of Guardians. He died at his residence, 37 Uttoxeter New Road, Derby, on the 2nd July, 1903.

Mr. Taylor was elected an Associate Member of the Institution on the 3rd February, 1885.

CHARLES GEORGE WILSON, after serving an apprenticeship of seven years, from 1843 to 1851, under Sir John Anderson, was employed by various engineering firms and railway companies. At

the commencement of the Crimean War Mr. Wilson joined the expeditionary force sent against the Russian forts of Petropavlovski. In 1854 he proceeded to India, and was employed by Mr. C. B. Ker as an Assistant in the Locomotive and Carriage Department of the Great Indian Peninsula Railway. In 1856 he became Assistant to Mr. James Berkley, Chief Engineer of the line, with whom he remained three years. In 1860 Mr. Wilson was appointed 2nd Class Assistant Engineer on the Bombay and Baroda Railway, in which capacity he had responsible charge of works in various districts.

In 1863 he returned to England, and was subsequently engaged on his own account and for his brother, Mr. James Wilson, on various engineering works, railway surveys, etc., and as Assistant Engineer for the Central Northern Argentine Railway. In 1873 he went to Japan as one of the principal Railway Engineers for the Japanese Government. He liked the climate, the people and the country so much, that he wrote home he did not think he should ever return, and he died there on the 11th April, 1902, in his seventy-fifth year.

Mr. Wilson was elected an Associate of the Institution on the 3rd February, 1874, and was subsequently placed among the Associate Members.

HENRY WILLIAM YOUNG died at his residence, Cowper Street, Greymouth, New Zealand, on the 4th August, 1903.

Born at Camberwell, London, on the 31st October, 1840, he went to New Zealand in 1863, and to the West Coast in 1865 to join his brother Mr. R. A. Young, now of Westport, who had arrived a few months earlier. The brothers remained on the goldfields until 1873, when they settled in Greymouth, the partnership lasting for about eight years, during which time they acted as engineers for many important works for the Government and for various local bodies. As architects they also designed the Greymouth, Hokitika, and other large public schools and ecclesiastical buildings, including Trinity Church, Greymouth. In 1878 the firm were appointed engineers to the Westport collieries, and in that capacity designed and carried out the railway and the famous Denniston incline, at the time a new departure in engineering work. The firm were also associated with Mr. Napier Bell in the construction of the Cape Foulwind Railway and of portion of

the Westport Harbour Works, of which Mr. R. A. Young is now engineer. For a couple of years Mr. H. W. Young was in Wanganui, and in 1886 he accepted the appointment of Chief Assistant Engineer in the colony for the Midland Railway Company, being directly under Mr. Napier Bell, and subsequently under the late Mr. Robert Wilson, acting as Engineer-in-Chief during Mr. Wilson's absence from the colony. Mr. Young's appointment was of ten years' duration, lapsing only with the cessation of operations by the Company. Since 1896 he was in private practice as engineer and architect, and in both capacities was associated with nearly every important work or building on the coast. In social life his genial, kindly and hospitable disposition made him popular with all.

Mr. Young was elected an Associate Member of the Institution on the 5th March, 1889.

JAMES NEILSON, C.B., one of the Managing Directors of the Summerlee and Mossend Iron and Steel Company, died at his residence, Orbiston House, Belleshill, Lanarkshire, on the 6th October, 1903, in his sixty-fifth year. Born on the 1st May, 1838, he was one of a family which had been closely identified with the iron industry in Scotland for more than a century. In addition to his connection with the Summerlee and Mossend Company, he was a Director of the Caledonian Railway Company, of the Lanarkshire and Ayrshire Railway Company, and of the Ardrossan Harbour Company, and Chairman of the Lanarkshire and Dumbartonshire Railway Company. He was also Chairman of the School Board of the parish of Bothwell for many years and of the District Committee of the Lanarkshire County Council, and he held the rank of Colonel in the "Queen's Own" Glasgow Imperial Yeomanry.

Colonel Neilson's services as a volunteer were so remarkable as to warrant special mention. He joined in 1855, and in 1865 served with the regiment in aid of the Civil Power during some riots at Airdrie, and was never absent from a training. He raised and equipped the 18th Company Imperial Yeomanry, consisting of 121 men and 5 officers for service in South Africa. Colonel Neilson raised amongst his friends upwards of £4,000 for the better equipment of this Company, and out of his own pocket supplied each of the men with serge tunic, trousers and field-cap, for use on board ship and stable duties. When additional Yeomen for service at the front were called for, he raised 609 men, so that altogether he sent to

South Africa 730 men. For his services in connection with the Yeomanry he was created C.B. in 1902.

James Neilson was elected an Associate of the Institution on the 6th December, 1898.

THOMAS HENRY SALE, Colonel R.E. retired, who died at his residence, 147 Gloucester Terrace, Hyde Park, on the 13th December, 1903, aged 89, was the oldest officer in the corps of Royal Engineers. Son of the late Mr. Richard Cowlishaw Sale, Clerk to the Grand Junction Canal Company, he was born in London on the 8th December, 1814, and was educated at Westminster and at Addiscombe. He was appointed to the Bengal Engineers as Second Lieutenant in December, 1830, and after the usual course at Chatham joined the Sappers and Miners at Delhi in 1832. After surveying the cantonments of Agra and Muttra, he was employed on public works in districts extending from Peshawar in the north-west to Sylhet and Assam on the east, and Jubbulpur towards the south. In 1856 he was appointed Superintending Engineer in Bengal, and three years later he retired and from that time lived in London. Colonel Sale was a good geometrical draughtsman. In later life he became a collector of pictures and curios. He married in 1848 Miss Maria Ravenhill, of Cheetham Hill, Manchester, and is survived by his only child, Mrs. Shawcross, wife of the vicar of Chadwell Heath.

Colonel Sale at the time of his death was third on the roll of seniority of the Institution, of which he was elected an Associate on the 2nd June, 1840.

*** The following deaths have also been made known since the 15th August, 1903:—

Members.

BRAMWELL, *Sir* FREDERICK JOSEPH, *Bart.*, D.C.L. (*Oxon*). LL.D. (*Cantab*), F.R.S., Past-President; *died* 30 November, 1903.

DAWNEY, CHARLES; *died* 9 December, 1903.

KNOX, EDWARD BALDWIN JOHN; *died* 5 December, 1903.

McCLELLAND, WALTER SIMPSON; *died* 1 January, 1904.

MARTIN, EDWARD JAMES; *died* 24 November, 1903.

MOLINE, LEWIS PRICHARD; *died* 12 January, 1904.

PEARSON, HENRY WILLIAM; *died* 20 October, 1903.

STANTON, JOHN HARRISON; *died* 1 January, 1903.

Associate Members.

BARRATT, HENRY; *died* 20 January, 1904.

BIRT, RUDING SPENCE; *died* 25 November, 1903.

CRAWFORD, WILLIAM FREDERICK, B.A. (*Dubl.*); *died* 8 October, 1903.

HASELDEN, EUGENE KINNAIRD; *died* 19 January, 1904.

MATHEWS, EDWARD DAVIS; *died* December, 1903.

VIVIAN, HENRY ANDREW; *died* 25 January, 1904.

Associates.

BARKLIE, ROBERT MARTIN, *Colonel R E.; died* 30 August, 1903.

NEWTON, FRANCIS MURRAY; *died* 16 August, 1903.

Information as to the career and characteristics of the above is solicited in aid of the preparation of Obituary Notices.—SEC. INST. C.E., 4 February, 1904.

Sect. III.

ABSTRACTS OF PAPERS IN SCIENTIFIC TRANSACTIONS AND PERIODICALS.

The Creeping of Rails. F. J. Allen.

(Railroad Gazette, October, 26, 1903.)

The Author records the mode of dealing with creeping rails on the Chicago, Burlington and Quincy Railway, U.S.A.

On double-track railways, the heavier and faster the trains the more the rails will creep. This is especially true on steep down-grades, where all trains maintain high speed. The pilot-wheels of an engine are always running uphill regardless of the gradient, and it is this that pushes the rails forward, or, in other words, causes creep. Other and minor causes tend to produce the same effect in a smaller degree. On single-track railways the rails do not creep entirely in one direction, as on double tracks. The effects of creeping are varied. Where there are cross-overs between parallel tracks the switches and frogs move in the direction of the traffic, necessitating their being replaced, in order to preserve the proper alignment of main track. Where railways cross on the level, especially at points where there are several parallel tracks, the effects of creeping are serious. The Author cites an instance where there are eight tracks in one direction and six in the other, making 48 crossings, and shortly after new crossings are put in, they are all out of line in both directions. At crossings on double tracks. where trains run at high speed, it is absolutely necessary to keep all tracks in proper alignment. To do this it is necessary either to prevent creep or to be constantly cutting rails or using short pieces, and moving crossings back to their original position. Under certain conditions the rails on one side will creep more than on the other, and this has a tendency to displace the sleepers, so that they are no longer at right angles with the rails. This causes a tightening of the gauge and produces an irregular line, causing kinks which are readily perceptible to the eye. Rails creep more in warm than in cold weather. This is accounted for by expansion of the rails which forms tight joints, making an almost solid rail for long distances.

The best remedy which has been found is to lay the rails with broken joints, with heavy angle-bars[1] slotted at each end for

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[1] This treatment refers to the flat-footed rail universally used on American railways.

spikes, and to place an anchor on the middle of each rail, opposite the joints, where 30-foot rails are used. This gives an anchorage every 15 feet, and greatly reduces creeping. The anchors can also be applied to the middle of rails with laid "square joints" by placing anchors directly opposite each other, so that they can be spliced to the same sleeper, but broken joints are preferable. For the anchor the Author uses a section of standard angle-bar 5 inches long with a hole drilled through it and slots cut out for the spikes. A hole is drilled through the rail and the 5-inch sections of angle-bars are put on the rail in the same way as for a regular angle-bar, and are also spiked in the slots to the sleeper. The Chicago, Burlington and Quincy standard angle-bars are 38 inches long making a "three-sleeper joint." The angle-bars are slotted so as to make an anchor on the two outer sleepers near the ends of the angle-bars. About opposite one end of the angle-bar, and on the same sleeper which is anchored by the slot in the angle-bar, the 5-inch anchor often is placed and spiked to the same sleeper. This device has proved in actual practice during the past 16 years to greatly reduce the creeping of rails, and it tends to hold the rails in their proper position. It is used on all the double-track lines of the Chicago, Burlington and Quincy Railway.

Bushing Railway-sleepers for the Reception of Spikes.

W. FRIDERICIA.

(Bulletin of International Railway Congress, October 1903, p. 901, 1 Fig.)

The Author found that the resistance to drawing spikes was increased nearly 100 per cent. by the following means:—A hole (much larger than the diameter of spike) is bored in the sleeper, not necessarily right through it, but with a depth equal to the length of the prismatic part of the spike shank. Into this hole a smooth bush of nearly cylindrical shape is driven, this bush being made of hard wood and with a diameter a little larger than the hole in sleeper. In the bush there is a small hole $\frac{5}{16}$ inch to $\frac{11}{32}$ inch diameter which need not go right through. The spike is driven into this bush, the fibre of the hard wood being parallel to the spike and at right angles to the fibre of the sleeper. After a number of trials it was found that to draw the spike out of such a bush required about twice as much pull as in the case of a spike driven into a sleeper direct, and the pull required even exceeds that required to draw a screw spike.

Among the advantages claimed are (1) that the destruction of sleepers by spike holes gradually working larger will be greatly lessened; and (2) that sleepers which may have been rendered unserviceable by spike holes, having commenced to decay or

having become worn, although otherwise sound and good, may be bushed and replaced in service again.

A successful trial has been made of the method in the neighbourhood of Copenhagen on a line over which the quickest trains run, and using new sleepers as well as old ones in which there was slight decay.

After more than a year's continuous observations of the 300 bushes tried it was found that, (1) not one spike had shifted even to the extent of 1 millimetre (0·04 inch); (2) not a single bush showed any tendency to separate from its sleeper. The sleepers used in the trials were chiefly of pickled Baltic pine; but other kinds of timber were tried.

The Author claims that the method described is essentially different from that employed by Mr. Albert Collet on the Paris-Lyons-Marseilles Railway.[1]

J. M. M.

Hand-locking in Railway-Signal Work. WEGNER.

(Organ für die Fortschritte des Eisenbahnwesens, 1903, p. 6.)

The author discusses the use for railway purposes of a description of lock which he terms a "wechselschloss" or reciprocal lock. This is an automatic apparatus which maintains two keys in such interdependence, that it is only possible to remove one key at a time from the apparatus. In this case the freeing of a key is a proof that the arrangement is locked in a pre-determined position. The applications of such a lock are very numerous. One of the most simple is for level-crossing gates. Under ordinary circumstances many such gates have to be kept locked at night, but if the adjacent occupiers are provided with keys bearing their names, which keys can unlock the gates by means of a reciprocal lock, but cannot again be withdrawn from the lock unless the gate is closed and locked, an efficient check is provided on the closing of the gate and the objections to permitting the use of such level-crossing gates at night largely disappear. These locks can easily be applied to facing points, where not connected to a cabin. For outlying sidings also they may be useful in obviating the necessity for a cabin. The author gives the following example: A station on a double line had the points into the goods sidings worked by ground levers, that is, they were not connected up by rodding to a central cabin. For a certain period there was only one official at the station, and the absolutely essential duties required did not allow of his leaving the main building for such a length of time as was necessary to attend to the arriving of goods trains and their admission to the

[1] Minutes of Proceedings Inst. C.E., vol. clii. p. 358.

sidings. In this case these locks were called into service; they were used to lock the points opening on the main line, and also the skotch block on the siding close to the main line. When a goods train arrived the guard opened the door of a small cabin at the side of the line by means of an ordinary carriage key. Here he found a piece of apparatus which enabled him to communicate with the adjoining stations. With their permission he got possession of a key with which he unlocked the points, and, the unlocking of the points releasing a key for unlocking the skotch block, admission was finally gained to the sidings. The author discusses the application of these keys to the securing of a series of points in the forming of a "road" through a station-yard or elsewhere. In the ordinary method of using hand-locks the number of keys free at one time would be equal to the number of points, but, by the author's system, only one key would be free at any one time, thus simplifying matters considerably and avoiding risk of mislaying keys. Applications to stations in various circumstances are further described. Cases are also instanced where points were arranged to be opened either from a cabin or by ground levers, the operations being controlled in the latter case by these reciprocal locks.

J. G.

Self-acting Couplings for Railway Trucks. SAUER.

(Annalen für Gewerbe und Bauwesen, No. 632, 15 October, 1903, p. 151 *et seq.*).

This is a full account of the trials conducted on the 12th February, 1903, by Messrs. Krupp, of Essen, with a set of 17 truck-ends fitted with different examples of couplings. The trucks are arranged in the form of a diagram to explain the nature of the apparatus and, of many of the chief couplings, detailed photographs have been prepared in order to demonstrate the mode of working. The various types are classified under (*a*) couplings with the usual system of screw-fastenings, but with special clutches, and (*b*) couplings with projecting self-acting coupling-boxes. The mechanical details are in all cases described and explained by reference to diagrams. Trials of coupling and uncoupling were made both on straight roads and on curves with a radius of 109·3 yards. Three practical tests were conducted with each apparatus and these trials included passing over the tongue of a crossing, hauling tests on changing gradients, break tests and collision tests on sidings, when the trucks were dashed into the stop-blocks. In these last experiments the trucks provided with buffers proved their superiority over those which were close-coupled without buffers. Special attention is given to the line of grip in the clutches, and the experiments proved that it was feasible to adopt a hook-shaped grip, without interference

with the possibility of readily attaching or detaching the coupling head. A diagram is appended to show how the line of wear would be affected in an improved form of clutch. The American system is fully considered and is described with diagrams. The various kinds of detaching gear are discussed, as are also the relative advantages and disadvantages of coupling at the buffer-level and below the floor line of the truck. The general conclusions are that these mechanical coupling arrangements effect a great saving of time and are to be preferred from the points of view of humanity, economy and security for the traffic.

G. R. R.

Lighting of Railway Carriages by means of Incandescent Gas.

H. GIRAUD and G. MAUCLÈRE.

(Revue Générale des Chemins de Fer, May, 1903, p. 265.)

Realising the value of incandescent lighting from the point of view of economy as well as of illuminating power, the Eastern Railway of France conducted a series of experiments in order to determine whether it was practicable to adopt this system for the lighting of railway carriages. Preliminary laboratory tests were made to find if possible an incandescent material of a less fragile nature than the ordinary mantle, but no practical results followed, and the mantle was adopted. A detailed description is given by the Authors of the first series of tests taken in suburban trains, the results of which proved that it was unnecessary, and even harmful, to use chimneys for the mantles; also that a mantle of small dimensions should be used in order that its solidity might be increased. Several different elastic suspensions were tried, but it was found that the mantles broke less quickly on the least flexible supports, and in the end elastic suspensions were given up altogether, and the burner was screwed directly on a jointed swan neck, which was generally fitted with a Manchester burner. As a result of these tests it was decided to make a further series of tests in express trains under the following conditions:—

(1) An increase of the pressure of the gas which was estimated in the earlier tests to be between $4\frac{3}{4}$ inches and $5\frac{1}{8}$ inches of water in order to obtain a sufficient draught of air.

(2) The limitation of the hourly consumption of the burners to between 0·49 cubic feet and 0·53 cubic feet of rich gas.

(3) A lighting power not lower than 14 candle-power.

Three lamps fulfilling these conditions were fitted in a first-class carriage on an express train, and the mantles lasted from 50 days to 111 days, corresponding to a mileage of from 13,000 miles to 30,500 miles, and gave every satisfaction as far as the lighting power was concerned, with the result that the tests were extended,

and one of the carriages was fitted up with oil gas at a pressure of 100 lbs. per square inch, and at the same time second- and third-class carriages were submitted to the tests. Tables showing the results of these tests in detail are given. Forty lamps were used, of which twenty had "Auer" (Welsbach) mantles, and twenty "Lumen" mantles. The "Auer" mantles had an average life of 51 days, were lighted for an average period of 409 hours, and had an average mileage of 15,600 miles against corresponding figures of 49 days, 475 hours, and 19,900 miles for the "Lumen" mantles. Forty-five per cent. of the mantles were withdrawn intact as far as the tissue of the mantle was concerned, and were replaced on account of a diminution of their illuminating power, an inconvenience which is not observed in the later mantles of an improved form. It was also noticed that not one of the mantles broke in course of travelling. The following comparative table is given of the different systems of lighting employed:—

Mode of Lighting.		Hourly Consumption.	Lighting Power.
			Candle Power.
Colza oil lamp, faucon system	oz.	0·6	8
Rich gas without recuperation	cubic feet	0·88[1]	5
" with recuperation	" "	0·88[1]	9
" with incandescent mantles	" "	0·53[1]	19
Compressed oil-gas with incandescent mantles	" "	1·23[1]	17
Electricity with accumulator batteries, 1st class	watts	36	12
" " " " 2nd "	"	36	12
Electricity, system Auto-generator Vicarino 1st class.	"	48	16
Electricity, system Auto-generator Vicarino 2nd class	"	36	12

[1] Measured at atmospheric pressure.

In conclusion the Authors state that for a period of ten months, twenty-one compartments have been lighted for about 18,000 hours without any accident, and at the same time gave a light twice as strong as the lamps with recuperation, and a reduction in the consumption of gas of 40 per cent.

Full particulars of the various lamps used are given with several figures.

J. A. T.

Lighting of Railway Carriages by means of Incandescent Gas.

(Revue Générale des Chemins de Fer, June, 1903, p. 390.)

Referring to a previous article[1] on the system of lighting of railway carriages by incandescent gas used by the Eastern Railway of France, a brief description is given of the system adopted by the Western Railway of France, which differs in one or two important details from that adopted by the Eastern Railway. The burner used is placed in the lamp upside down, and the incandescence is made by means of a small mantle, almost spherical in shape, suspended from the lower part of the burner. The rays of light are directed to the ground, and nearly all the light produced is thus utilised. With a delivery of 0·53 cubic feet of rich gas per hour, the lighting power given is 30 candle-power, whilst with the same delivery, the ordinary burner of the "Auer" (Welsbach) kind gives only about 20 candle-power. The tests taken have given such satisfactory results that the Western Company are installing this system on their suburban trains. A section of the lamp is given.

J. A. T.

The Power-Stations for the Brussels Tramways. J. Reyval.

(L'Eclairage Electrique, November, 1903, p. 201.)

The system of tramways operated by the "Société des Tramways Bruxellois" has in recent years grown very rapidly, partly by ordinary extensions and partly by the purchase of lines formerly operated by other companies. This has made necessary the building of a new central power-station, which is described in great detail in this Paper. The plan adopted for the distribution of power to the enlarged system is to generate all the power required at high tension in the new station, and to use the old stations as sub-stations where the pressure can be transformed down to a value suitable for supply to the lines. The new building is erected at Anderlecht, on the bank of the canal from Charleroi to Brussels, and by means of an aqueduct water is led from the canal to supply the circulating pumps for the condensers of the engines. In the station there are four generators, each having a capacity of 1,500 kilovolt-amperes at 6,600 volts, and each coupled direct to a horizontal compound-engine. The frequency is 25 at normal speed, and the alternators have an efficiency

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[1] See foregoing abstract.

of 96 per cent. for power-factor unity, and an output of 1,250 kilowatts. There are three sets of exciters, one set driven by a steam-engine, while the other two are driven by motors taking current from the mains at 6,600 volts. The special feature of the switch-board is that all the high-tension switches, which are of the oil-brake type supplied by the General Electric Company of New York, are operated from a distance by small continuous-current low-tension servo-motors. The boiler-room contains 10 Babcock and Wilcox boilers in 5 groups of two. At the sub-stations the pressure is converted by static transformers, each of 200 kilowatt capacity, from 6,600 volts to 410 volts alternating, and thereafter by 6-phase rotatory converters from 410 volts alternating to 550 volts continuous.

W. C. H.

The Graphic Calculation of Arches with three Joints.

JACQUIER.

(Annales des Ponts et Chaussées, 1903, p. 265.)

Arched bridges, with three joints, present many advantages over other types, and their conditions of resistance can more readily be determined. The calculation of such conditions is very laborious by ordinary methods, as an example of which, the Author draws attention to a memoir, by Messrs. Résal and Alby, upon the Alexander III. bridge. The employment of "lines of influence" allows such calculations to be very considerably reduced, and as the method is but little used, the Author considers it would be useful to set out same in a short Paper. He defines a "line of influence" as a curve, of which the ordinates represent the effect produced in a determined section by a load, of which the abscissa is the same as that of a point in the curve; and considers this effect from the point of view of bending moments, normal effort, the work of compression or tension, and work of deformation. In the fifth section of the Paper he applies his formula to the calculations of the bridge Alexander III., and tabulates the results obtained; comparing them finally with those worked out by the engineers of the bridge: and shows that, in spite of some differences, caused partially by the limits of overload not being exactly the same in the two methods, the results agree.

The Paper is illustrated by various graphic figures in the text, and one plate.

H. I. J.

Bridges of Concrete and Steel. J. E. Ribera.

(Revista de Obras Públicas, vol. 51, p. 85.)

The construction of bridges of concrete and steel upon a system invented by the Author has found considerable favour in Spain, and the Revista publishes a long series of articles dealing with the methods of design, and certain examples are also given and illustrated. One such example is a horizontal girder bridge at Renteria. This type is recommended for bridges up to 52·5 feet span, and the Author states that this type of girder-bridge is from 20 per cent. to 60 per cent. cheaper than a bridge of equal strength built of metal alone.

The pre-existing timber bridge at Rentaria was removed and replaced by the concrete and steel construction in 25 days. The span was 46 feet, and the total width 10·5 feet. Three girders were thrown across, each 3·28 feet deep, the central one 12·6 inches wide, and the side girders 12 inches wide. A cross section is given, which shows that on the tension side of each beam were embedded two steel rails, weighing 60 lbs. per yard, and on the compression side two bars of 0·78 inch in diameter. The upper and lower pairs were laced together and the whole surrounded with concrete, which is solid with the road bed.

The structure was calculated for a uniform load of 59·4 lbs. per square foot and a moving load of 5 tons upon one axle. A test-load of 99 lbs. per square foot was applied and carts loaded to 5 tons were driven over. The cost of the work is not stated, but a full account of the calculations is given.

E. R. D.

The Displacement of the Passy Footbridge over the Seine. J. Feugères.

(Le Génie Civil, September, 1903, p. 321.)

The Outer Circle Metropolitan Railway of Paris will cross the River Seine in two places, the one at Passy, and the other at the Bridge of Bercy. The position selected for the former of these crossings coincides exactly with the site of the existing foot-bridge, and the design adopted for the new structure consists of a viaduct of two storeys; the railway being carried on one level and the passengers and the vehicular traffic on the other. In order to prepare for the new bridge it was necessary to remove the present footbridge; but, as this is the only means of communication between Grenelle and Passy, it was impossible to do away with the bridge entirely. It was decided, therefore, to shift the bridge bodily down the stream, a distance of 98·4 feet, rather than incur the

cost of a temporary wooden bridge, while the new works were in progress. At the place where this bridge crosses the Seine the river is divided into two arms by the Isle of Swans. The traffic on the wider branch of the river is very considerable, and the bridge, which is 393·7 feet long and of somewhat uncommon design, consisted of an arched central span in two parts, keyed together in the middle, and two half arches, forming the approaches on either side. These arches all rested on two sets of twin-piles driven into the river-bed, and on masonry piers on the island and on the river bank. By reference to plans and photographs, the Author explains the system adopted for moving the structure, the total weight of which was estimated at 320 tons. Wooden piers were built up round the piles and at the shore ends and extended to form stages along which the entire bridge could be rolled, and, when all things had been prepared, the structure, resting on cradles, was lifted by means of screw-jacks about 8 inches. This enabled the workmen to insert rollers beneath the cradles, and the next day six winches, each manned by four workmen, which were attached to the bridge with cables, and were together capable of exerting a tractile force of 48 tons, sufficed to move the bridge along the rolling-way, which had been duly prepared, and to transport it to the new position. The whole operation, with 30 stoppages, lasted 4 hours, and was effected without any difficulties or interruption to the navigation. The removal of the bridge over the smaller arm was carried out on an entirely different plan. In this case sand-barges were moored beneath the bridge, on each of which a timber staging was erected, and the superstructure, having been divided in the centre, was dealt with in two distinct operations, one half being moved each time. The barges were ballasted with sand, and when all things were ready part of the ballast was discharged, and the barges, as they rose, lifted the bridge off its bearings, enabling it to be readily shifted to the new temporary supports prepared for it. All the operations are fully explained by reference to the illustrations.

G. R. R.

The Luxemburg Bridge. D. Bellet.

(La Nature, 22 August, 1903, p. 177.)

An account is given of the new bridge over the Valley of the Pétrusse at Luxemburg, opened on 5 August. This bridge, constructed in the hard stone of the locality, contains several novel features. The central arch, with a span of 277·7 feet, rises to a height of 137·7 above the level of the river, and the thickness of the masonry at the crown of the arch is only 4 feet 8 inches. The height from the foundation-level to the crown of the arch is 101·7 feet. An appearance of lightness is imparted by the use

of open-work spandrills, filled in with an arcade of four arches on either side. Another singular detail in the design is that the bridge is not continuous throughout its width, but is in reality composed of two twin arches, each 16·4 feet wide, with a span between them of 19·68 feet. This space is to be filled in with a layer of re-enforced concrete, resting on either arch and destined to carry the central roadway of the structure. By this means, the total weight of the masonry has been reduced by one-third. As a result of this system of twin arches, it has been possible to employ a single centreing for both arches; this was supported on dwarf walls specially prepared to receive it and to form a slip-way, along which it was moved, after the first of the two arches had been completed. Details are given of the mode of constructing the centreing, which weighed nearly 300 tons, and of the erection of the temporary bridge, which was provided for the execution of the work. It is pointed out by the Author that the success of this stone bridge of such an unusual span, indicates the possibility of a future competition with metal-work for bridge construction. An illustration is given of the finished structure.

G. R. R.

The International Navigation Congress of 1902. *Reports of the French Delegates.*[1]

(Annales des Ponts et Chaussées, part 1, 1903, p. 1.)

The ninth International Congress on Navigation, held at Düsseldorf, was attended by six French delegates, each of whom has reported on some particular question submitted to a section of the Congress.

Mr. Barbet, in the first section, "Inland Navigation," reports on the question, "The means of compensating for great differences in levels, and an examination of the best examples of an artificial navigable way adapted for such purpose." In Chapter I. an abstract is given of fourteen reports on this question, the points dealt with embracing inclined planes, vertical lifts (both electrical and hydraulic) and locks; and also deals with the question of the provision of water for maintaining levels. Chapter II. deals with the general discussion and the resolutions passed, and Chapter III. gives a general summing up of the points raised, and remarks thereon, by the Author of the Sectional Report.

Mr. Chargueraud reports on "Tolls on Navigation" in Section I. Chapter I. gives an abstract of eight reports on the question, the principal points being:—The possibility of covering the outlay on inland navigable ways and ports, and the upkeep of same, by the charging of tolls on navigation, and the best means to attain

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[1] Minutes of Proceedings Inst. C.E., vol. clii. p. 196.

same; what circumstances aid or hinder the attainment of this end; whether such an end can be attained by undertaking either the haulage of the traffic, or the entire provision of carrying facilities. Chapters II. and III. are devoted to the discussion, resolutions passed and a general summing up, as in the first report.

Mr. Georges Lefebure reports in the first section on the question, "The diminution in the value of coal and coke due to its carriage by boat." Chapter I. gives an abstract of seven reports on the question, the principal points dealt with being:—The transport to the port; its loading, carriage and discharge; its storage in warehouse, and generally the damage sustained both by water and rail carriage. In Chapters II. and III. are given the substance of the discussion, the resolutions passed, and the general summing up of the Author.

In the second section, "Marine Navigation," Mr. Joly reports on "The relative cost of building, and upkeep of gates in wood and iron." Chapter I. gives an abstract of six reports, which deal with the durability; facility for effecting repairs; cost of repairing and maintenance; and ease in putting in place and replacing. In Chapters II. and III. are given a general report on the question, the discussion, conclusions adopted by the Congress, and a general summary by the Author.

In the same section Mr. Guérard reports on "Carriage by seagoing lighters," five reports being presented for discussion. The principal points were:—The class of traffic specially adapted for boats which can navigate the sea, and also inland rivers and canals; the best modes of construction for such purpose; what are the advantages and disadvantages inherent to such traffic from a public and economic point of view; the economical limits of such traffic; and the encouragement by Government of such traffic by means of special tolls. Chapters II. and III. give the discussion and resolutions passed, and a general summing-up by the Author.

In the same section Mr. Barbé reports on "The equipment of repairing docks," four papers being dealt with on the question of the relative advantages of dry and pontoon docks. A description is given of the principal Continental dry and pontoon docks. Chapters II. and III. deal with the discussion on these papers, the resolutions passed, and the Author's summing-up of the whole question.

H. I. J.

Improvement of the Rhine Wharfage at Düsseldorf.

WALRAFF.

(Zeitschrift für Vermess gswesen, 1903, p. 143.)

The Author states that during the last 12 years a sum of about £1,000,000 has been spent by the municipal authorities upon improvements in the wharfage, and docks on the Rhine at

Düsseldorf. The work may be divided into three parts; from 1890 to 1896 the new harbour on the up-stream side of the town was built, from 1896-8 the down-stream quays and the bridge, and from 1899 to 1902 the centre part of the quays were constructed.

The Author gives a description of the topography of the Düsseldorf district, from which it appears that opposite Neustadt, near Düsseldorf, the level of the bed of the Rhine is 65·6 feet below sea-level, whereas that of the bed in the section between Düsseldorf and Cologne is only about 9·84 feet below the same datum. The new harbour is divided into two parts, one for the petroleum trade and the other for ordinary commerce, and the entrance is on the concave side of the large bend in the river at the town. The total area of the harbour is 32 acres and the cost was £500,000.

Commerce has increased from 33,559 tons in 1895 to 620,301 tons in 1900; the number of vessels from 4,798 to 7,465, and the railway wagons used for harbour trade from 17,062 to 47,646.

The Author then deals with the new bridge, and describes the relative advantages of three sites which were considered; the bridge has a total length of 695 yards, with 6 arches, the two principal having spans of 198 yards. The total width of the bridge is 46·6 feet, of which 26·9 feet is devoted to the roadway and 9·84 feet each side to the side walks. Work was begun in the spring of 1896 and completed in November, 1898, and the total cost was about £300,000.

The quays are next dealt with, and work began upon them in May, 1899, and the Author describes the difficulty of obtaining sound foundations in such a deep part of the river, and the methods employed. The total cost of these quays from the petroleum harbour to the Kohlentor was about £175,000. The article gives a concise account of the progress of public works in this town during the past 12 years, which culminated in the Exhibition of 1902.

E. R. D.

The Charles-River Dam. John R. Freeman.

(Report of the Committee on the Charles River Dam, Boston, 1903.)

This Volume contains the report of the Committee of the Senate and House of Representatives of the Commonwealth of Massachusetts, on the proposed Charles-River Dam; together with that of its chief engineer, Mr. John R. Freeman, and various experts. They collected information with regard to the feasibility and desirability of building a dam across the Charles River at, or near, Craigie Bridge, and a mass of data with reference to sewage overflow, harbour conditions, &c. It also contains, in the form of an appendix, preliminary designs of Mr. Freeman for a dam provided with a lock having a depth of 18 feet over the sill at low water, and special sluices. Six designs for such a dam of varying cost,

together with estimates and the cost of the marginal conduits and embankment walls are given.

Mr. Freeman recommends the construction of a high dam, with a roadway and drawbridge, which would allow the passage of tugs and mastless vessels without opening it.

The committee recommends that the dam should be built with a roadway across it, 130 feet wide, and sufficiently high to keep out all tides, so that a freshwater basin at nearly constant level would be formed, and would be available for purposes of recreation. By locating the dam at Craigie Bridge, the proposed basin would extend through the thickly-populated districts, and the cost of rebuilding the old bridge would be avoided.

To prevent any objectionable contamination, the engineer recommends that all direct sewage and factory waste be taken out of the Stoney Brook Channel and out of the Charles River, between Waltham and Craigie Bridge; and that a marginal conduit, on the Boston side, should be built to discharge below the dam, and be made of sufficient capacity to convey the entire flow of Stoney Brook, and the storm overflow from all the neighbouring sewers in all but one or two of the worst storms in the average year, except during the hours of extreme high water. It would be provided with tidal sluices at its outlet. On the Cambridge side he recommends that the overflow channel from Binney Street should be continued below the dam, with similar arrangements for discharging. This would deal with the sewage overflow and street washings from 33 per cent. of the area, and 58 per cent. of the population of Cambridge, which at present discharge into the Charles River above the Craigie Bridge.

The apportionment of the cost between the various public bodies interested is dealt with.

A. W. B.

Mechanical Towage on the Nivernais Canal. MAZOYER.

(Annales des Ponts et Chaussées, 1903, pt. 1, p. 368.)

This Paper gives the results of the first year's working of mechanical towage, by means of a sunk chain and petrol motor, on the summit level section of the Nivernais Canal, between the basins of Poujats and Port-Brûlé, a distance of 4,500 metres (4,950 yards). Owing to the construction of the canal, with tunnels and a narrow path only, haulage by human labour has hitherto been obligatory.

During the first year towing has been in operation on 219 days, 762 loaded boats carrying 55,355 tons having passed along the canal; in addition to which 357 empty boats have been hauled free of charge. The mean time per journey has been 95 minutes, and

the mean tonnage of each convoy 63·2 tons. The total general expenses have been 4,590 francs (£191 5*s.*), of which petrol cost 3,590 francs (£149 12*s.*). The cost per kilometric ton was 0·022 francs (0·22 pence), and per horse-power hour 0·26 francs (2·6 pence). The receipts from the traffic show a total deficiency of 1,873 francs (£78 10*d.*). The Author points out that the results of the second half-year show a great improvement over the first half-year, and that with an increase in the traffic, the service should be self-supporting. In any case, however, he considers that the development of the traffic in the district, and the saving of the former hard-labour in propelling the boats, well warrant the annual outlay in keeping up the towage service.

H. I. J.

Electric Towing on the Erie Canal.

(Electrical World and Engineer, N.Y., November 14, 1903, p. 795.)

This paper gives a brief description of a system of electric towing now being tried on an experimental track, about 2,700 feet long, on the bank of the Erie Canal at Schenectady. It is a monorail system, each line consisting of an 18-inch girder supported a little distance from the ground by short posts set in concrete at a distance of 25 feet from one another. The girder more remote from the canal is raised above the inner one, and the two are cross-braced to stiffen the structure. The upper and lower edges of each girder are faced with light 3-inch rails for track. One trolley wire carried by brackets, which are supported on poles set at the outer edge of the tow-path, serves both tracks. The electric locomotive 10 feet long and 2 feet wide, and rising to a height of 3 feet from the track, closely resembles in form that commonly used in mines. It carries at each end a 40-HP. motor, taking current from the line at 475 or 500 volts. Each motor drives a grooved wheel about 22 inches in diameter, running upon the upper rail, the ratio of the gearing being about 40 to 1. In addition to these driving wheels on the upper rail, there are on the under rail two running-wheels supported from the locomotive by a heavy arm, and made to press upwards and grip the rail by means of springs. The additional adhesion given by this arrangement virtually doubles the traction effect due to the weight (over 5 tons) of the locomotive. In the actual tests two loaded barges, giving together a weight of nearly 600 tons, have been hauled at a speed of 4½ miles per hour; and again, four loaded barges have been hauled at the same time at various speeds up to the same figure. The absence of wave-motion, or of wash on the canal-bank, was very noticeable, and this result is accredited to the steadiness of the breast pull and to the abolition of the screw propeller. The cost of equipping the Erie Canal, 352 miles long,

with this system is estimated to be about £1,500,000. An estimate, made by the company undertaking these tests, of the probable gross earnings, operating expenses, and net earnings per annum on this system, is also published in this Paper.

W. C. H.

Electric Towing on the Miami Canal.

(Electrical World and Engineer, N.Y., November 14, 1903, p. 804.)

On the Miami Canal from Cincinnati to Middletown, a distance of 42 miles, a system of electric towing involving the use of polyphase currents has been introduced. This Paper gives an outline of the principal features of the undertaking. Three-phase currents are used, but only two trolley-wires are required, as the track serves as the third conductor. The locomotive takes current from the line at 1,170 volts, and transforms it to 390 volts, for use in the motors. Each locomotive weighs 55,000 lbs., is 14 feet long, 8 feet 4 inches wide, and has a wheel base of 7 feet. The bridges across the track restrict the height to 8 feet 6 inches, which has been made the standard height, but one switching locomotive, used at the Cincinnati end of the line, is only 5 feet 6 inches high, and therefore has a cockpit for the motor-man instead of the ordinary cab. Each locomotive carries a plug switchboard, transformers, a rheostat, and two 80-HP. 3-phase induction-motors, one geared to each axle by double reduction. Normally the motors are operated in tandem—i.e. current from the transformers is supplied to the stator of the first motor, which has its rotor connected to the stator of the second motor, while the rotor circuit of the latter is closed through a controller and iron-grid resistances. By this controller the speed can be varied, but the maximum at present allowed by statute, 3 miles per hour, is attained by the normal running of the motors in tandem, and at that speed each motor gives 40-HP. and a horizontal effort, with 25 per cent. co-efficient of adhesion, of 9,600 lbs. The track is laid with 70-lb. rails, and the locomotives may be used for haulage of goods waggons on the line as well as for towing barges.

The standard boat is 80½ feet long, 13½ feet broad, and has a depth of 9 feet, or, if decked, a clear height of 7 feet 8 inches in the hold. If loaded to a depth of 3 feet, these boats can carry about 65 tons, but, owing to the condition of the canal bed, the present practice is not to load deeper than 30 inches, and in this condition the boats carry about 50 tons.

W. C. H.

Accidents to Steam Boilers.

(Annales des Ponts et Chaussées, 1903, part 1, p. 351.)

This Summary, compiled from the Official reports, relates to accidents to steam boilers in France during the year 1901.

The total number of accidents was 36, of which 11 occurred with non-tubular boilers, 14 with tubular boilers, 7 with water tube boilers, and 4 with steam receivers.

The Summary gives the date of the accident; nature and situation of the boiler; general details of its construction; and particulars, consequences, and presumed cause of each accident.

A further summary divides the accidents under the heading of:—(1) Nature of the work for which the boiler was used. (2) Construction of the boiler. (3) Presumed cause of the accidents. Under this last heading the accidents are sub-divided: defective conditions of construction causing 6 accidents, defective conditions of repair 19 accidents, improper usage 12 accidents, and causes unknown 3 accidents. This gives 40 causes for 36 accidents, two causes having contributed to one accident in four cases.

Five sheets of detail drawings containing 81 figures, illustrate the constructional details of the various parts of the boilers causing the accidents.

H. I. J.

The Steam Turbine. A. Stodola.

(Zeitschrift des Vereines deutscher Ingenieure, 1903, p. 1, *et seq.*)

This Paper is practically a treatise on steam-turbines, extending to over 50 pages of the "Zeitschrift." The Author begins with a consideration of the thermodynamics of steam moving in a stream. When steam issues from a simple opening in a thin wall, the velocity cannot exceed the velocity of sound moving in the same medium, and therefore the pressure in the opening only sinks to a little over the half of the initial pressure, and the total fall cannot be made use of. In order to render the total pressure available for speed, De Laval applied a conical nozzle and the Author undertook a series of experiments to obtain reliable data as to the effect of nozzles of various shapes and under different circumstances The principal point in these investigations was the measuring of the steam pressure at points along the outside of the stream of steam and in the centre, at various points from the narrow to the wide end of the nozzle. The Author gives his results in the form of tables and diagrams. Following on this, the Author conducted a series of experiments with a specially-constructed model turbine in order to determine the pressure of the steam in front of the guide blades and that on the wheel blades, the latter being at rest.

Both the tangential and axial components of the pressure were measured. The Author next takes up the strength of rotating disks, the novel parts of his treatment being the consideration of disks of unequal thickness and disks of uniform strength. The question of the highest permissible speed is dependent upon the strength of the material, and Krupp, of Essen, recommends a nickel steel of 90 kilograms per square millimetre (57 tons per square inch) strength, 12 per cent. ultimate extension on 100 millimetres (4 inches) and 65 kilograms per square millimetre elastic limit (41 tons per square inch). It is possible, however, to obtain small nickel steel forgings of an ultimate strength equal to 200 kilograms per square millimetre (127 tons per square inch) and an elastic limit of 160 kilograms per square millimetre (102 tons per square inch), but the ductility is proportionately less. As regards the permissible stress, Krupp's opinion is that, for like stresses, one-third of the elastic limit stress may be allowed. The Author next considers the vibration of rotating disks, and discusses the methods of obtaining permanent axes, the strength of turbine shafts, the steam friction of rotating disks, giving tables showing that the resistance under no load increases quickly with the specific weight of the surrounding steam, and that the advantage gained by the increase of the diameter and peripheral speed, with the corresponding increase of the hydraulic efficiency, may very easily be counterbalanced by the increased resistance shown by the rise in the work required to run the turbine under no load.

The Author here enters upon the theory of the steam turbine, pointing out that the usual analytical method of treating the calculations of the compound turbine is very cumbersome; he then develops a graphical method more suited to the requirements of practice. Regarding the efficiency of a turbine, the Author defines first the thermodynamic efficiency referred to the effective performance as

$$\eta_e = \frac{L_e}{L_o}$$

L_e is the work done, not including steam and journal friction, for a definite initial condition of steam and definite vacuum; L_o is the work that would be done by an ideal frictionless turbine, in which the energy of the steam is fully utilised, the velocity on leaving the last blades being zero. L_o is the same as the work which would be performed by a frictionless reciprocating engine with no friction in the steam passages, non-conducting cylinder walls and no clearance spaces. The Author puts

$$L_o = \frac{\lambda_1 - \lambda_2'}{A}$$

λ_1 and λ_2' are the initial and final heat of the steam (per kilogram), adiabatic expansion being supposed; A is the heat equivalent, in calories, of one metre-kilogram of work = 1/424. The total heat

expended, Q_o, is of course greater than AL_o, and approximates to λ_1, depending on the feed temperature. The total efficiency is

$$\eta_o = \frac{AL_e}{Q_e}$$

L_e is calculated from the following formula (for saturated steam)

$$K = \frac{6 \cdot 87 - 0 \cdot 9 \log p_2}{\log\left(\frac{p_1}{p_2}\right)}$$

p_1 and p_2 are the initial and final pressures in kilograms per square centimetre. K is in calories, and L_e is obtained from K by the aid of the following formula:—

$$L_o = \frac{270{,}000}{K} \text{ metre kilograms}$$

The Author then describes the different systems of turbine construction, giving also data as to the performances. In comparing the steam turbine with the reciprocating engine, he comes to the conclusion that the turbine has reached such a development as to render it more economical in steam consumption than the compound piston engine with moderate superheat. It is not yet, however, equal to the triple-expansion engine. For the 5,000-h.p. turbine to be erected at Frankfort by Brown, Boveri & Co., the makers guarantee a steam consumption of 4·9 kilograms (10·78 lbs.) per effective h.p. at the turbine shaft. Compared with this, the 3,000-h.p. triple-expansion engines at the Berlin Electricity Works are 8·3 per cent. better. Stated in another way, the Frankfort turbines are to expend 3,500 calories per effective h.p. per hour as against the 3,230 calories of the Berlin engines.

The Author finally discusses in a few pages the future out look for heat engines.

J. G.

Alcohol Motors. E. Meyer.

(Zeitschrift des Vereines deutscher Ingenieure, 1903, p. 513.)

The Author was one of the judges appointed to settle between the merits of a number of alcohol motors by different makers, brought together through the agency of the German Agricultural Society. There were eight firms competing, with ten motors of about, on the average, 14 nominal HP. In starting the motors, benzine was used, and in about 4 minutes the full load could be applied, the motors by that time working with the alcohol

alone, which contained 86 per cent. by weight of pure spirit. The duration of the trials was about 2 hours for each motor. The smallest consumption of alcohol was 352 grammes (15 fluid ounces) per brake HP. per hour. The results of the tests are given in tabular form, each motor having been tested under maximum load, normal load, half load and with no load. The Author found by experiment that the figures obtained during the trials were not absolute, in this respect that the alcohol used per brake HP. might vary under the same load, depending on the amount of opening of the admission valves for spirit and air. Tests were made to determine the amount of this variation for each motor; in one case the Author was able to work one engine at 471 grammes (20 fluid ounces) of spirit per brake HP. per hour, while the public tests had given 529 grammes (22·5 fluid ounces) as the most favourable consumption.

Another factor which affects the consumption of spirit is the amount of compression, and, to obtain a proper comparison of the motors, the Author calculated the amount of spirit that would have been consumed if the ratio of compression had had the constant value of eight to one for all the motors. In the case of two motors of the same power and similar in construction except that the ratios of compression were different, the Author found that the consumption of the one with the smaller ratio, 5·91, was 436 grammes per HP. per hour, and the calculated consumption for the machine with the higher compression of 8·9 on the basis of the data obtained with the first machine was 377 grammes, which compared well with the actual consumption of 364 grammes. The Author discussed the question of limits of compression, pointing out that alcohol possesses greater possibilities in this respect than benzine or petroleum, for which excepting in the Diesel motor, the ratio of compression cannot well be carried beyond 4 to 1. Some of the spirit motor diagrams are reproduced and discussed in detail. The thermal properties of the mixture of alcohol, water and air which is exploded in the cylinder, are also fully discussed. The calorific value of the 86 per cent. spirit used in the trials is taken by the Author at 5,500 calories per kilogram (2,590 B. Th. U. per pint). The total efficiency of the motors was calculated from the expression $\frac{632}{S_e \times 5{,}500}$ in which 632 is the number of calories in one HP. hour, and S_e is the consumption of oil in kilograms per brake HP. per hour. The highest efficiency obtained was 32·7 per cent. by the Marienfeld motor, but the others were not very much less. This efficiency is about double that of an ordinary petroleum motor, and the Author accounts for the great difference by the higher ratio of compression possible with the alcohol motor (10) than with the ordinary petrol motor (4), and the fact that with spirit a high temperature is not required for the taking up by atmospheric air of sufficient alcohol vapour. As regards costs, spirit, benzine and petroleum are all

about equal—for prices of oil and alcohol in Germany—the cost of the oil or spirit alone being 0·9 pence per HP. per hour. The Diesel motor is not included in this statement.

J. G.

Heat Engines and Liquid Fuel. RUDOLF DIESEL.

(Zeitschrift des Vereines deutscher Ingenieure, 1903, p. 1366).

The Author, comparing the total efficiencies of different heat engines, puts the efficiency of the 3,000-HP. triple-expansion steam-engine in the Berlin Electricity Works, working at 12·3 atmospheres (175 lbs. per square inch) pressure, with 314° C. of superheat, at 15·7 per cent. The corresponding figures for power gas-engines, alcohol-motors and the Diesel oil-motor are respectively 20 per cent., 32·7 per cent. and 35·7 per cent. With respect to this last figure, the Author indicates that this is higher than is turned out in the actual general practice of works, and he states the efficiency of the Diesel engine in another part of the Paper at 32·6 per cent. Comparing internal-combustion motors as regards cost of fuel, he gives the costs for explosion-motors using alcohol, benzine or petroleum, at from 4·35 to 4·5 pfennige (about a halfpenny) per HP. per hour, while the cost for the fuel of the Diesel motor using paraffin, raw oil or gas oil, is 1 pfennige (about half-a-farthing) per HP. per hour. The two most important of the figures that give this result are the total efficiencies and costs of the fuel. The costs of fuel are, as given by the Author: 20 to 21 pfennige per kilogram (1·13*d.* per lb.) for alcohol, 24 pfennige per kilogram (1·31*d.* per lb.) for benzine, 22 pfennige per kilogram (1·2*d.* per lb.) for petroleum, and 8·25 to 10 pfennige per kilogram (0·45*d.* to 0·55*d.* per lb.) for the gas oil, etc., used for the Diesel motor. The efficiencies are: For the spirit-motor, 32·7 per cent.; for the benzine-motor, 20·5 per cent.; for the petroleum-motor, 17·6 per cent.; and for the Diesel motor, 32·6 per cent.

The Author says that the present movement (in Germany) to apply alcohol for power purposes in motors is an entire mistake. The Diesel motor can be driven with alcohol as well as with oil, and there is no reason why it should be driven with alcohol, even although this fuel is a product of German agricultural industry. Even although the present German tariff on petroleum were raised to three times its present amount, the Diesel motor would develope power as cheaply as alcohol-motors. The price of liquid fuel in Germany is more than double the price in most other countries, owing to the tariff.

Descriptions with drawings are next given of various different makes of the Diesel engine, and also examples of its application for different purposes.

The Author then turns to the general question of liquid fuels, giving data as to the distribution of oil wells over the surface of the earth, discussing the prospects of its supplanting coal for ship propulsion, etc. The tariffs and prices in the different countries are also shown in tabular form, the Author remarking that under the present conditions it is easy to see that Germany must suffer through the price of fuel oil being so much higher for her than for most of her competitors in industry.

J. G.

Experiments with a Diesel Oil-Motor. E. MEYER.

(Zeitschrift des Vereines deutscher Ingenieure, 1903, p. 637.)

The Author commences by a description of the two motors which he investigated, one 70 HP. and the other 8 HP. Detail drawings are also supplied. The oil used was of two kinds—Russian petroleum weighing 8·06 lbs. per gallon and paraffin oil weighing 8·93 lbs. per gallon, made from German brown coal and being much cheaper than petroleum. The 70-HP. motor was tried with both kinds of oil, and while the calorific value of the paraffin was only 2½ per cent. less than that of the petroleum, the amount used for the same power was about 7 per cent. in excess of the amount of Russian oil required. The calorific value of the latter oil was taken as a minimum at 10,300 calories per kilogram (4,723 B.Th.U. per pint).

The highest brake power developed by the 70-HP. motor was 86·65 H.P. corresponding to 109 HP. indicated in the cylinder. Allowing for the work expended in driving the air-pump, the mechanical efficiency was 81·4 per cent. The oil used per brake HP. per hour amounted to 188 grammes (8·2 fluid ounces); this was the best result obtained in the fourteen tests. At half-load this amount increased to 224 grammes (9·8 fluid ounces). The corresponding figures for the 8-HP. motor were: at full load, 219 grammes (9·6 fluid ounces) and at half-load 260 grammes (11·4 fluid ounces), in each case per brake HP. per hour. Diagrams taken during the trials are reproduced in the paper, and the Author points out that the diagrams taken continuously one after the other, exhibit only one outline; thus showing the remarkable regularity and uniformity of the motor. The thermal efficiencies, ratios of indicated work to total heat (work) of fuel, of the 70-HP. motor at full, normal, three-quarters and half-load, were respectively 40·1, 40·4, 41·7 and 41·4 per cent.; the same figures for the 8-HP. motor were 35·3, 35·7, 39·8 and 37·6. The total efficiencies or ratios of brake-power to equivalent in work of total heat of fuel were; for the 70-HP. motor at full, normal, three-quarters and half-load, 32·6, 31·9, 30·5, and 27·4 per cent.; the corresponding figures for the 8-HP. motor were 28, 27·6, 26·2,

23·6. The Author remarks that the highest total efficiency of the 70-HP. motor, 32·6 per cent., is practically equal to that of the Marienfeld 14-HP. spirit motor, namely 32·7.

J. G.

Experimental Freezing Station. C. LINDE.

(Zeitschrift des Vereines deutscher Ingenieure, 1903, p. 1,071.)

The Author here reviews shortly the main results obtained at the experimental station at Munich instituted for conducting investigations with refrigerating and cooling machines. One set of tests on five different machines using ammonia in compression was remarkable as shewing the highest relative performances that have ever been known for any description of freezing plant. The chief measurements during the tests were the quantities and temperatures of the brine and the cooling water. The heat taken from the brine was returned by a steam-heating arrangement. The efficiency of cooling plant may be stated in two ways, first, with the temperature T_s of the brine at the outlet in the refrigerator, and the outlet temperature T_k of the cooling water on the condenser side as the temperatures of reference, and, second, taking, instead of these, the temperatures corresponding to the pressures of the saturated ammonia vapour in the refrigerator and condenser respectively, viz: T_1 and T_2. With the latter temperatures the expression for the efficiency of a cooling plant is

$$\eta' = \frac{W}{A\,L_i} \cdot \frac{T_2 - T_1}{T_1}$$

W is the quantity of heat abstracted at the refrigerator, and $A\,L_i$ is the thermal equivalent of the work indicated by the compressor. For the eight series of tests the efficiencies, stated at per thousand, vary from 659 to 806. The ratio of the two efficiencies η and η' is, of course, the efficiency of the heating and cooling surfaces, η being a similar expression to η' but with T_s and T_k in place of T_2 and T_1. The efficiency η generally reached its maximum value with a brine temperature of about $-5°$ C., a very important circumstance, seeing that the greater proportion of existing freezing plant works at this temperature of heat abstraction. The details of the determinations made in each of the eight tests are given in tabular form.

One of the problems solved at the experimental station was the quantitative determination of the working of the carbonic acid machine. The heat W taken up in the refrigerator of such a machine when m kilograms of carbonic acid have completed a cycle is given by the following formula—

$$W = m\left(r_1 + \frac{0{\cdot}0625}{\sigma'} - \frac{0{\cdot}0625}{\sigma_1} - 0{\cdot}182\,(t' - t_1) - A\,p_2\,\sigma' + A\,p_1\,\sigma_1\right)$$

In this formula r_1, σ_1, t_1 and p_1 stand for the latent heat, specific volume, temperature and pressure of the carbonic acid in the refrigerator; σ', t' and p_2 the specific volume, temperature and pressure of the carbonic acid in the condenser. Investigation was made as to the use of nitrous oxide as a working fluid, and the results were very favourable, as shewing that more cold could be produced for the same power expended than with carbonic acid, and generally that the physical properties of nitrous oxide are more favourable for freezing machines than those of carbonic acid, the only advantage of which in practice is its cheapness. The fractional distillation of liquid air, and the separation of the contained nitrogen and oxygen, were also successfully effected at the testing station.

J. G.

Safety-Catches in the Dortmund Collieries. HARTE.

(Glückauf, 1903, p. 729.)

A great variety of safety catches are in use in the collieries of the Dortmund district. They may be divided roughly into two classes, those with a sudden action and those with the action of a brake. The former, which are designed to hold the cage, when the winding rope breaks, by grips clutching the guides, are the more usual, and are represented by the White and Grant, the Fontaine, the Libotte, the Hypersiel, the Fritz, and wedge catches. The second class is represented by the Lohmann, the Münzner, the Lessing and the Gerlach and Boemke catches. Between 1890 and 1902 the safety catches used came into action 117 times in raising coal and failed 53 times, and nine times in raising men and failed once, the total being 126 successes and 54 failures. The experience hitherto obtained is not unfavourable to the efficacy of safety catches. They have acted much more often than they have failed. On several occasions lives have been saved, whilst there is no instance on record of serious injury having been caused by the catches having acted. It is impossible to decide which of the catches mentioned is the most trustworthy. The value of safety catches in general cannot, however, be ignored. In order to ensure proper action, care must be taken that the guides are strong enough to withstand the shock of the free falling cage, and that both the guides and catches are kept in good repair.

B. H. B.

Blast-furnace with Continuous Slag and Metal Discharge.

A. BRATKE.

(Stahl und Eisen, 1903, p. 1033.)

This paper describes a method invented by T Stapf, of constructing blast-furnaces in such a manner that the slag and metal, instead of accumulating for several hours, flow out continously after a certain fixed depth of the hearth has been filled. The principal feature in the method is the use of variously shaped spouts or channels inclined upwards from the lowest points of the slag and metal outlets in the hearth where the molten materials stand at sufficient height to seal the passages against the gaseous and other pressures of the contents of the furnace. This in the case of the slag, is confined to the gas pressures prevailing at the higher level, while the metal is subjected to the weight of the column of slag in addition. When, therefore, these heights are adjusted to the average working conditions of the furnace, the slag and metal as they accrete will flow out continuously, and may be disposed of as required, the former by granulation, and the latter either by casting into pigs on a casting-machine, or by storage in a reservoir or mixer. The advantages looked for in the system include greater regularity in the descent of the charges, the column in the stack never being deprived of support by emptying the hearth, whil the blast is kept on continuously instead of requiring to be stopp . during the casting period, and in furnaces of large make, only . comparatively small casting machine will be required. Thus a 50 -ton furnace, tapped at intervals of two hours, discharges from 40 to 42 tons of metal in a period of 2 to 5 minutes, and to cast this directly, the chain of moulds would require to travel at the rate of 60 to 70 feet per minute, which is about four times the speed found to be safe in practice. It is therefore necessary to tap the metal into ladles and carry them to the casting-machine at a distance, about 50 minutes being required for the casting of the two hours make. With the continuous discharge, the output of the furnace corresponds to an increase of 140 kilograms filled every 24 seconds, and therefore the casting-machine need not move at a higher speed than 2½ feet to 3 feet per minute when handling 500 tons per day. The plan has been tried on a small scale by the Author at Trofoijach in Styria upon a charcoal blast-furnace making 30 tons to 35 tons per day, and the experiments were so far successful as to demonstrate the possibility of obtaining a regular flow from the two openings, but in no case was it possible to go on continuously for any length of time owing to defects in the design and materials of the arrangements, which were necessarily of a somewhat makeshift character, the furnace, beside being encumbered with heavy brick pillars about the hearth had been in blast for more than seven years, and was nearly worn out, and any repairs and alterations had to be made in the short intervals

between tapping—about 3 hours. The furnace has since been blown out, and in relining provision is made for automatic slag and metal outlets on opposite sides of the hearth with the ordinary tap hole and slag tuyer in front for use in the event of accidents.

H. B.

Duff Producer-plants for Heating and Power-gas.

H. BRAUNS.

(Stahl und Eisen, 1903, p. 1191.)

This is an illustrated description of the Duff producer plants at work or in course of erection at the Armstrong-Whitworth works in Manchester, the Parkhead Forge, Glasgow, and the United Alkali Company's works at Fleetwood. Of these the first two each include ten producers gasifying 200 tons of coals per day, and supplying fuel for steel-melting and heating-furnaces, and for gas-engines of 500 to 1,000 HP. They are essentially low-temperature producers, a large quantity of steam being admitted with the air, and the gas progressively cooled and passed through absorption towers and scrubbers to save ammonia, after which the bulk of it goes to the furnaces, only so much of it as is required for power purposes being subjected to a further special purification. The average composition of the gas is CO_2, 15; CO, 12; H, 23; CH_4, 2; N, 48 per cent.; the thermal value is 1,142·7 calories per cubic metre, which, for purposes of comparison with ordinary producers, must be diminished by the amount required to raise its temperature from 60 to 500 degrees, or 143·4 calories, leaving 999 calories as the available heating power. With ordinary bituminous slack containing about 1·25 per cent. of nitrogen, 1 ton of ammonium-sulphate is obtained from 24 tons of coal, with a total outlay of £15 2*s.* 6*d.*, against a selling price of about £12 10*s.*, the difference, £2 12*s.* 6*d.*, representing the cost of the available fuel-gas.

In the large producer plant, built by the Author at the Dortmund Union Works in 1894, the gas, which leaves the producers at 500 degrees temperature, contains CO_2, 4; CO, 22; H17, 3; C_2H_4, 2; O, 0·05 per cent., with a thermal value of 1,356 calories per cubic metre, or about 35 per cent. higher than the Duff gas. With this richer gas an expenditure of about 5·2 cwts. of coal is required to melt a ton of steel costing 2*s.* 7*d.*, while with the plants at Manchester and Glasgow an equivalent quantity of gas for the same work, allowance being made for its lower calorific value, is obtained for about 9½*d.*, and they would show an advantage over the ordinary system so long as the price of ammonium sulphate does not fall below £6 6*s.* per ton. The ammonia-saving plant cannot, however, be advantageously used when the coal consumption is less than 40 tons per day. The amount of coal

gasified in the existing Duff producers in England is about 234,000 tons per annum, the large plant in course of erection at Fleetwood is of the capacity of 100 tons daily.

Another very large application of the system is being made for power purposes in Spain, the plant being intended to supply 10,000 HP. to the Central Electric Station at Madrid.

The author in conclusion considers that although the basic Bessemer process will continue to hold the principal place in Germany as a means of producing soft steel, the great saving in fuel obtained by the Duff process, coupled with the large size furnaces used in the Talbot process, may, in the interest of economy, render it desirable to adopt the open-hearth process to a greater extent in future.

H. B.

Thermal Efficiency of Crucible Melting-Furnaces.

F. Wust.

(Stahl und Eisen, 1903, p. 1138.)

The following experiments were made in melting bronze in a single-pot furnace, heated with coke and a fan-blast; the air being passed through a jacket space formed between the fire-brick body and an outer sheet-iron casing of the furnace before coming to the grate-bars, whereby its temperature was raised about 100°. This for the 12 kilograms of air required in the oxidation of 1 kilogram of coke corresponds to 288 calories, or about 4 per cent. of the heat developed by the combustion of the coke—a result which in no way bears out the great economy of fuel claimed for this construction. The actual increase of heat in the melting chamber may be about 70°, which is of some importance, but the loss by unconsumed carbonic oxide in the flue-gases is notably higher with hot than with cold air, especially when soft coke is used. In the first experiment, the charge of 100 kilograms, including $\frac{2}{3}$ old metal, $\frac{1}{3}$ new copper, and tin in the proportion of 9 of the former to 1 of the latter, was melted down in 1 hour 15 minutes. The coke consumed was 35 kilograms, and the second 100 kilograms of old metal requiring 1 hour 35 minutes, and 50 kilograms of coke. During both, the temperature of the waste gases were taken at several intervals by a calorimeter, and found to average 973° and 1058° respectively, and samples drawn off by an aspirator for analysis gave the following results—

	CO_2	CO	O	N
First experiment . . .	13·2	3·5	3·2	80·1
Second „ . . .	10·5	7·3	2·3	79·9

The average composition of the coke was: carbon, 87·76; sulphur, 1·0; ash, 8·98; moisture, 0·40 per cent.; and its heating power 7,635 calories.

The heat contained in the molten metal was determined by pouring 680 grammes into a calorimeter containing 9 litres of water. It worked out to 1,850 calories per kilogram of metal, or about 4·8 per cent. of the total heat developed by the coke.

The results of the calculation, expressed in terms of the total heat, are as follows:—

	Experiment I.	Experiment II.
Carried away in flue gases	38·8	43·1
Loss by incomplete combustion	15·5	34·5
Utilized in melting and heating metal . .	6·9	4·8
Absorbed by crucible and furnace walls, and loss by radiation and conduction . . .	38·8	17·6
	100	100

The first of these items is not, properly considered, a loss, as temperature of the escaping gases must necessarily be about the same as that required to keep the metal sufficiently hot for pouring, or not below 1,000°. It is, however, different with the second, where the great difference between 15·5, or 34·5 per cent. in the two experiments is caused by the higher production of carbonic oxide through the reducing action of coke upon carbonic acid when the furnace and air are hotter. The use of hot blast under these conditions seems therefore to be prejudcial to economy.

H. B.

Utilization of the Waste Heat of Crucible Melting-Furnaces.

E. Schmatolla.

(Stahl und Eisen, 1903, p. 1229.)

This is a note on an arrangement of melting furnaces for the purpose of utilizing the waste gas of the furnace described in the preceding abstract. It consists of three melting holes placed in a straight line, the outer ones being fired with coke and forced draught, while in the centre the heating is done by the carbonic oxide in the waste gases coming from either side. These are burned by air warmed in a continuous recuperator placed in the current of the chimney gases. With this combination, when the coke-fuel furnaces were each melting from 7 to 8 charges of 150 kilograms in the shift of 10 hours, a further number of six casts were obtained for the central one without any fuel other than that obtained from gases ordinarily wasted, a result which shows the irrational character of the melting arrangements in current use even when working upon the so-called most modern systems.

H. B.

New Method of Compacting Steel Ingots. JULIUS RIEMER.

(Stahl und Eisen, 1903, p. 1197.)

The Author, after reviewing the different methods of preventing piping in large steel ingots by pressure, either from above, as in the Whitworth method, or from below by forcing the metal while still plastic into a narrower part of the mould, the so-called wire-drawing system of Harmet, describes a new method of preventing the formation of a top crust on the ingot until the metal below has become solid. This is done by placing upon the top of the mould a neck lined with fire-clay, and above this a dome-shaped cover, having a central passage above for filling the mould, which is connected laterally with a rectangular chamber forming a fire-box, the whole being lined with refractory material. When the mould is filled the feeding aperture is closed with a loose cover, and producer gas and air previously heated are introduced through independent pipe-connections into the combustion chamber at the top, when the flame filling the space, enclosed above the metal in the mould, prevents the latter from chilling and setting at the top before that below it has consolidated. Any contraction therefore is fed up by liquid steel from the more highly heated portion above. Two forms of the arrangement are described. In the first, which is intended for the smaller sizes of ingots, the waste flame escapes into the air from openings in the domed cover, but in the second form used with heavier (20 to 60 tons) ingots the waste heat is utilized by causing the flame to pass through a system of passages in the casting forming the sides of the construction, arranged parallel with others, bringing in the air and gas in opposite directions. The gas used is taken from the producers supplying the melting and heating furnaces, the air is supplied by a fan-blower. Preliminary heating is, however, necessary for both, as the essential of the process is the production of a temperature considerably above the melting heat of steel as rapidly as possible, and for this purpose iron pipe-testing stoves are used.

Illustrations are given of ingots weighing 24½ tons, 45 tons, and 11½ tons respectively, which have been subjected to the process, together with sections of the unsound parts cut off the top in either case. These represented 7·0, 5·3 and 7·2 per cent. of the weights as cast, or not more than would be cut off an ingot under ordinary favourable conditions of working. The heating was continued with the largest ingot for about 1½ hours, but this seems to have been the least successful experiment, the heat developed by the flame not having been sufficiently high. In the other two cases the heating was continued for 40 and 30 minutes, the arrangements having modified, to enable the gas and air to be more strongly pre-heated.

As the appliances required for the process are of a very simple character, the cost of the equipment is small, and need not exceed

£700 to £1,000 for a large steelwork, the working cost according to the extent of the operations may be from 6*d.* to 1*s.* per ton. And as the waste in scrapping unsound ingot tops may be reduced from 30 per cent. to 40 per cent. to 5 per cent. to 10 per cent. of the weight cast, ingots heated by this method may be considered to be worth 7*s.* 6*d.* to 9*s.* per ton more than those cast and cooled in open moulds in the ordinary way.

H. B.

Further Investigations respecting Nickel Steels. Léon Guillet.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 30 August, 1903, p. 208.)

These experiments were undertaken with a view to ascertain the nature of the "martensite" in raw nickel steels. The subject was obviously a difficult one, because, before knowing the character of the martensite in special steels, it was necessary to determine this question in the case of the ordinary steels with carbon. It seemed probable from the Author's previous investigations that the element nickel was capable of assuming the properties of the martensite. The various tests, together with the results obtained, are detailed, and, by reference to a shaded diagram, the conclusions are set forth, and the influence of nickel upon the structure of the metal are explained. It appears probable that the martensite of nickel steels is one of a special type. The Author states that he has been enabled to prepare an extremely simple diagram for nickel steels, which is to some extent a translation of the experiments conducted by him. This diagram divides a square figure, in accordance with the percentage composition of the metal, into three triangular parts which coincide with varieties of steel possessing special properties. It must, however, be borne in mind that there are two secondary intermediate zones, also here indicated, which constitute to some extent the transitions from one category of steels to the other.

G. R. R.

Electric Welding by the Thomson Process.

L. de Kermond.

(L'Electricien, November 14, 1903, p. 305.)

This Paper gives a description of the process of electric welding introduced by Professor Elihu Thomson, and discusses its advantages as compared with those of the electric arc process. In using the latter method, the workman has to be protected against the

fierce light of the arc and the great heat developed by it, and even then he is hampered by the flame and smoke, and cannot readily keep his attention fixed constantly on the parts being welded. But this process has the further disadvantage that as the heat is supplied by an arc from a carbon road to the point of contact of the two surfaces to be welded, there is always an uncertainty whether the interior portions of the metal have been sufficiently heated to make the weld as solid there as at the surface. By the Thomson process all these objections are overcome. The pieces to be welded are held in clamps, and have their surfaces placed together. The clamps serve as terminals to be connected to a source giving the proper potential difference, and the resistance of the imperfect joint gives a large heating effect at that point. As the temperature increases, so does the resistance, giving a still greater heating effect, so that very soon the requisite temperature for a perfect weld is reached. The current is then switched off, and the two surfaces are pressed strongly together. As the heating effect of the current is as great in the interior of the metal as at the surface, the joint is made of uniform strength at all points of the cross-section. The Author describes and gives illustrations of some of the machines used in this process, and gives tables showing the power required, and the time taken to complete the welding of iron with iron, iron with steel, and copper with copper, the cross-section of the bars and tubes being given in each case. Only alternating currents are used, and a transformer is placed underneath the plate or table on which the welding process is carried out. An ordinary installation, giving a pressure of from 50 to 100 volts, may be used as the source of primary current if the secondary windings of the transformer are modified to suit such pressures, provided that the frequency is never less than 80, nor more than 250, periods per second. The Author indicates a great variety of manufactures, involving the joining of metals, to which the Thomson process may be, and is, advantageously applied. W. C. H.

Use of Thermit for Producing Sound Castings.

W. Mathesius.

(Stahl und Eisen, 1903, p. 925.)

In a paper read before the Eisenhütte Society at Düsseldorf, the Author describes several new applications of the Aluminothermic process of Dr. Goldschmidt, including the repair of defective castings, broken forgings, the joining together of rails and joists, and the production of sound castings in cast-iron and steel, both in ingots and castings to pattern. For cast-iron the material used is titanothermit, containing in addition to ferric-oxide and aluminium, a proportion of titanic acid, which, by the reaction during com-

bustion is reduced to titanium, and dissolved by the molten metal. The charge of this material is enclosed in a sheet-iron box at the end of an iron rod and plunged into the ladle filled with cast-iron from the cupola. The reaction begins almost immediately, and continues for about 1 or 1½ minutes, the heat developed being sufficient to produce a notable rise of temperature in the metal when the quantity is not below one ton. The castings are of a close grained texture, and the graphite scales separated are so small as to be scarcely perceptible. As titanium has the property of combining with nitrogen at the melting temperature of iron, any air bubbles that may be adherent to the flat surfaces of the moulds, are removed by absorption so as to give smooth castings of such surfaces a result which is not easily obtainable in the ordinary method of pouring. The proportion of thermit used may vary between ⅛ to ¼ per cent. of the weight of the cast-iron, the larger quantity being used with more valuable castings, or, when they are of small size, the corresponding cost is from 3 to 6 shillings per ton of metal.

In the treatment of steel castings, a conical funnel of fire-brick forms the top of the feeding passage, and a change of thermit of a special composition, contained in an annular iron box, is placed at the bottom of the funnel, the case being sufficiently strong to remain unmelted until the mould is completely filled, so that when the reaction takes place, the heat developed is concentrated within the funnel, keeping its contents melted and in a condition to fill up any cavity formed by contraction in the metal until the casting has solidified. This method has been very successfully used in the production of castings of large surface, and small section, such as the stems and stern-frames of steamers.

In another application to the prevention of piping in heavy steel ingots, which is a great source of loss in making large forgings, the mould filled in the usual way is allowed to cool until the steel has become pasty, when a charge of thermit is thrust by a rod down the centre of the mould to the lowest point where piping is likely to occur, or from one third to one half of the total depth. By the reaction a crater filled with liquid steel is formed at the top which progressively fills up the cavity formed by shrinkage below. The effect is rendered more certain by dividing the charge of thermit into two parts, which are placed one above another on the rod, the upper one being in a thicker case than the lower one. This delays the combustion of the former, with the result of continuing the heat development for a longer time, and transferring the effect to a higher point in the mould than could have been the case if the whole had been fired at once. Several ingots of 45 tons weight have been successfully heated by this method. From 12 to 14 kilograms of thermit costing 2*s.* per kilogram are required for this size, but for 10-ton ingots 5 kilograms at most issufficient. Among the examples given of welding by thermit, the most notable is that of the stern-frame of the steamer "Sevilla" of 9,000 tons, which was broken in a collision. The fractured surfaces which were at the

bottom of the inner stern-post and measured 20 by 8 inches, were united, without removing the stern-frame, by the expenditure of about 6 cwt. of thermite, while the ship was in dock in the beginning of March, 1902, and, after making several voyages when redocked five months later, the joint was found to be perfectly sound.

H. B.

The Alloys of Copper and Magnesium. O. Boudouard.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 30 August, 1903, p. 200.)

It is pointed out that Parkinson obtained an alloy of a yellowish red colour by fusing together 200 grammes of copper and 50 grammes of magnesium for about seven minutes. This alloy, which has a vitreous fracture, slowly becomes oxydised and is extremely brittle. The Author has undertaken a further examination of the alloys of these metals in a great variety of proportions. On constructing a graphic diagram showing the range of the temperatures of the melting points of all the different mixtures from pure magnesium melting at 635° C. to pure copper melting at 1085°, it is found that there are three maxima and four minima and many of the alloys are extremely fusible. All mixtures, in fact, containing up to 75 per cent. of copper have a melting point inferior to that of magnesium, and it is evident that it is possible to obtain three definite compounds $CuMg^2$, CuMg and Cu^2Mg. The alloys of copper and magnesium retain their white colour till the proportion of copper reaches 70 per cent. when a slight yellowish tinge is observable. At 80 per cent. the alloy is pale yellow in colour, and at 90 per cent. of copper it is fully yellow. Copper therefore loses its colour when its proportion is less than 80 per cent., and the same phenomenon was observed by Debray in the case of the alloys of copper and aluminium. A micrographic study of the various alloys follows, with photographic enlargements of the polished surfaces, with and without being acted upon by acids. Certain of the alloys were so extremely brittle that it was not possible to prepare micrographic specimens. It is observed that, in order to isolate the definite compounds of copper and magnesium, it is necessary to employ extremely dilute acid solutions and to prolong the attack for several days. A solution of hydrochloric acid in the proportion of one per mille was used in certain cases.

G. R. R.

Reconstruction of the Lichtenberg Waterworks.

E. PRINZ.

(Gesundheits-Ingenieur, November, 1903, p. 501.)

Lichtenberg, a suburb of Berlin, obtained its water supply in 1892 by means of a concession, under which a daily yield of 330,000 gallons was to be provided, but the works were to be laid out for a possible supply of 660,000 gallons. The right was reserved to the authorities of the town to purchase the undertaking on April 1, 1899. Before this date was reached notable deficiencies in the supply were apparent, and the quality of the water, owing to the imperfect purification from iron, was the subject of much complaint. The purchase-price for taking over the works was objected to, and litigation ensued, which lasted for more than two years, when matters were finally settled and the works were acquired by the authorities of Lichtenberg. By reference to a map indicating the vicinity of Berlin and the Oder valley, the situation of the works is explained as well as the positions of the water-works of the other outlying suburbs, which form a ring all round Berlin. All these works, as likewise those for the supply of Berlin itself, obtain their water from a sand-stratum, which traverses the ancient valley of the Oder and furnishes a vast volume of water at relatively trifling depths. By reference to plans and sections an account is given of the original Lichtenberg works, which consisted of a pumping-station with a plant on the Piefke system for the removal of the iron. These works have now been completely remodelled so as to furnish a maximum daily supply of 1,760,000 gallons freed from iron. An account is given of the mode of carrying out the new works, without interruption to the service, at a cost of £17,000. Sections are appended showing the borings and the geological formation of the subsoil, together with small-scale details of the covered reservoirs and of the filtering-plant.

G. R. R.

Reconstruction of the Paris Gasworks. E. BLUM.

(Journal für Gasbeleuchtung, 1903, p. 693.)

The recent reconstruction and extension of the Paris Gasworks has given the authorities an opportunity for introducing considerable improvements.

Formerly the retorts were horizontal, 10 feet long and set back to back. Careful consideration of the methods of working of other European gasworks led to the retention of the horizontal type in preference to the inclined one. At the same time, by

removing the partitions between the retorts, three were made 20 feet long, thus equalling in size the largest of the inclined type.

Such great length necessitated the use of mechanical charging machines. The two systems adopted are described in full: thus, in the turbine machine, the coal is fed from a hopper (carried on the travelling carriage) into a turbine and is run into the retort by centrifugal force. By an ingenious arrangement the speed of the turbine decreases automatically as the charging proceeds, so that the coal is deposited at gradually decreasing distances and so forms a uniform layer in the retort. When gasification is complete, the coke is pressed out of the retort by a telescopic stamp.

The second machine (Brouwers) is more portable, as the hopper runs on rails above the machine and is independent of it. The coal here falls into a leather strap running horizontally, and is thus slung into the retort. The adjustments for level, etc., can all be made by hand, only 12 seconds are required to effect charging and 3 H.P. is enough to drive the machine.

The article is fully illustrated by diagrams.

K. T.

Photometry of Incandescent Gas-Burners. Böhm.

(Journal des Usines à Gaz, 1903, p. 229.)

The article contains details of a further method of determining the candle-power of incandescent mantles. It consists in effecting a balance between the light of the standard and that of the mantle in three ways.

1. Put a green glass plate in front of standard and balance this against the mantle (the colours being now the same).
2. Put a reddish-yellow glass plate in front of mantle and balance against the standard.
3. Use both glasses simultaneously.

From these three equations can be determined the absolute candle-power, and experiments show that results are accurate to about 1–2 per cent.

If C = Candle-power of standard unshaded,
c = „ „ „ with green plate interposed;
X = „ „ Mantle, unshaded;
x = „ „ „ with reddish-yellow glass interposed;
$l:1$ the ratio of distances of mantle and standard from the screen in case 1;
$m:1$ the ratio of distances of mantle and standard from the screen in case 2;
$n:1$ the ratio of distances of mantle and standard from the screen in case 3.

Then the first test gives—

$$X = l^2C$$

Test 2 gives—

$$x = m^2C$$

Test 3 gives—

$$x = n^2C$$

or

$$X = \frac{l^2m^2}{n^2} C.$$

K. T.

Photometry of Flames of Different shades of Colour.

C. Fabry.

(Comptes Rendus, vol. cxxxvii., 1903, p. 743.)

In the ordinary photometric comparison of two sources of light of different colour, such as an electric arc and an ordinary standard flame, there is a considerable amount of uncertainty, and the Author proposes to eliminate this by using a secondary standard having exactly the same shade of colour as the light to be measured. Such standards can be readily obtained by using absorbent liquids through which the light from a standard lamp is made to pass. The Author uses two liquids, whose chemical composition is given, and which can be prepared easily, one of them acting as an absorbent of the rays corresponding to the red part of the spectrum, while the other absorbs the blue rays. By making the light from the lamp pass through different thicknesses of these liquids, an infinite variety of shades of colour can be obtained. The intensity of the light is modified as well as the colour, but the diminution produced by the absorption is determined once for all, and the ratio, which is a function of the thicknesses of the layers of liquid, may be given in a table or expressed by an empirical formula. To compare a source, L, with a standard, E, the Author first compares L with the light from a Carcel lamp modified by being passed through vessels containing layers of the absorbent liquids of the proper thicknesses to give the same shade of colour as L. When this comparison has been completed, L is replaced by E, new liquids are put in the vessels to establish once more an identity of colour, and measurements are once more taken. A simple calculation then gives the desired photometric ratio. The Author considers that this method, without introducing any serious complications, leads to greater precision and eliminates the great difficulties attendant on the present practice. An indication is given that fuller details will be published in a later Paper.

W. C. H.

Purification of the Sewage of Barmen and Elberfeld.

Dr. DUNBAR.

(Gesundheits-Ingenieur, 31 July, 1903, p. 336 *et seq.*)

The Author, who has had access to special sources of information, supplies details respecting the proposed method of dealing with the sewage of Barmen and Elberfield propounded by Mr. Lindley. The drainage of this district is partly on the separate system, partly ordinary water-carriage. The sewage water does not consist entirely of house drainage, but contains a notable proportion of soiled water from factories, and provision has likewise to be made for a portion of the rainfall. The maximum flow for Barmen is estimated at 330 gallons per second, and for Elberfield at 396 gallons per second. The distance between the farthest points of Barmen and Elberfield is about 7½ miles. Owing to the fall and the relative position of these towns, it is assumed that the maximum flow for the united district would amount to 660 gallons per second, and the mean total to 528 gallons per second. Provision has to be made also at the outfall for a rainfall equivalent to a flow of 110 gallons per second. Nothing definite is at present known respecting the composition of the sewage water, but the River Wupper, which is highly polluted, has only 30,000 to 45,000 germs per cubic centimetre, and from this it is argued that certain of the soiled water from factories must be of a germicide character. The body of the water carried down by the Wupper is relatively small, but it is intended to create an increased flow by means of storage reservoirs. Lindley discusses the various systems of treatment and the requisite tank-space for the clarification, and he gives in a separate report the results of a visit of inspection to England, when some of the chief sewage works were investigated. The Author comments upon the conclusions set forth in the report. The proposals for the new works involve a mechanical separation, which must be as complete as possible of the suspended matters; it must be practicable to employ chemical substances for precipitation; provision must be made for a supplementary treatment by some process of oxidation, and arrangements must be included for dealing with the sewage sludge. Details as to tank-area, cost of works and treatment, are also given. G. R. R.

Snow Removal by means of the Town Sewers. FORBÁT-FISCHER.

(Gesundheits-Ingenieur, 20 October, 1903, p. 469.)

In lieu of the costly plan of carting away the snow from the street-surfaces to the river or to the depôt, it has now become a usual practice to throw the snow, as fast as it is collected, into the

sewers, and this is done either by employing specially provided openings, or by making use of the existing manholes and gullies. From observations conducted by the Author, it would seem that even with an air-temperature outside of from 7° to 14° Fahrenheit, during periods of severe frost, the temperature of the sewer-water never falls lower than from 46° to 50°, which suffices to melt any reasonable quantity of snow, if proper precautions are taken to mix it gradually with the water in the sewers. An account is given of the arrangements made in Bremen, Cologne and Frankfort-on-Main for the admission of the snow into the sewers, and details are appended of the snow-pits or shafts, which have been specially provided. In some cases a jet of water is employed to aid in carrying away the snow. There are now of these special snow-chambers seventeen in use in Cologne and eight in Frankfort, and similar arrangements are introduced in connection with the sewers of Aachen, Halle and Wiesbaden. It has not been found that the solid matters and mud mixed with the snow, when the same is taken off the roadway in a partially melted state, cause any notable deposits in the sewers, but in order to make this system of snow-removal a success, it is expedient that the volume of water in the sewers should be relatively large. Attention is directed to the importance of making due provision for dealing with heavy snowfalls, in new schemes for the sewerage of towns, by the inclusion of a sufficient number of conveniently placed shafts, or snow-pits, with facility of access for carts, etc.

G. R. R.

Production of Oxygen from Liquid Air. C. LINDE.

(Zeitschrift des Vereines deutscher Ingenieure, 1902, p. 1,173.)

This process rests upon the fact that the oxygen and nitrogen of the air liquefy simultaneously under the proper conditions as to temperature and pressure, but that in re-evaporation the remaining liquid is always richer in oxygen, and the more so the further the evaporation proceeds. Thus, at the last moment before the liquid air has entirely re-evaporated, the liquid portion consists almost entirely of oxygen. The explanation of this is that while the freezing point of liquid air (at atmospheric pressure) is −191° C., the boiling points of oxygen is −182·5° C., approximately 13° C. higher than that of nitrogen, which boils at −195·5° C. As it is not so much pure oxygen that is desired, but atmospheric air with a large proportion of the nitrogen ballast removed, this process is suitable for technical purposes. In order to render the process economical, however, it is necessary to avoid the waste which there would be if the liquid air were simply evaporated and the cold produced allowed to escape into the air. To prevent this loss, the gas, as it is formed, is brought into contact with a stream of compressed air, which, after being thus cooled to a certain extent,

proceeds further and becomes itself liquefied by giving up its latent heat to the liquid air which is being evaporated. The work to be done in this case consists principally in compressing the incoming air and replenishing occasionally the supply of liquefied air. The Author here enters upon a description, with sketches, of the apparatus as it has been developed for practically carrying out the process. The first plant worked on a large scale had 150 HP. at disposal, and it was found that with an expenditure of 100 HP. there could be produced 100 cubic metres (3,532 cubic feet) of equal parts, by volume, of oxygen and nitrogen.

It was found impracticable at first to produce a gas rich in oxygen, but by adopting the principle of rectification, it has been rendered possible to reduce the proportion of nitrogen to 7 per cent. The further development of this process depends on the extent to which advantage is taken of it by industries.

J. G.

Removal of Domestic Refuse from the Hygienic Aspect.

Dr. H. Stakemann.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, 1903, p. 543.)

It is pointed out that the prevalent methods of dust-removal in many German cities are by no means free from objection in respect to the point of view of modern hygiene, and this arises chiefly from the fact that the dangers of a pollution of the soil, the water, or the atmosphere, are not nearly so great as those likely to be caused by defective arrangements for dealing with the excreta. A definition is given of the various substances which are comprised under the term of domestic refuse, and it is shown that the general composition fluctuates very widely, and depends upon the occupations and the relative wealth or poverty of the community. That portion which may be described as street refuse is a factor of very considerable importance in determining the manurial value of the compound; and the period of the year, the rainfall and the climate have a great influence upon the character of the refuse. The large amount of organic matter present renders this mixture very liable to putrefactive changes, and causes the same to be a source of danger to health, when accumulations exist in the vicinity of dwellings. Such refuse teems with germs, and in times of pestilence it may be the means of propagating epidemic diseases. Of all methods of disposing of house refuse the most objectionable is that entailing the employment of ash-pits or dust-holes, and the importance of using metal receptacles of small size, which can be emptied at frequent intervals, is insisted upon. The Author considers the various systems of utilising domestic refuse for agricultural and other purposes, and the plan of employing it for raising the level of low-lying areas. In some English sea-port

towns, it is thrown into the sea. The processes for burning up the refuse are investigated, and the difficulties and objections to the use of destructors and similar furnace-arrangements are discussed, but the Author considers this last to be the only system which complies with the requirements of hygiene. He sums up with the following conclusions: (1) Domestic refuse contains in many instances, infectious matters and the storing of the same for a lengthened period, or in large quantities, entails sanitary risks and serious dangers to health. (2) The collection and removal of rubbish should be undertaken by the local authorities and ought not to be entrusted to individual householders, or to private contractors. (3) The dust is best collected in light metal vessels of galvanised iron, which should be emptied into the carts during the night time. The removal should take place as often as possible and not less than twice a week. (4) The agricultural use of such refuse may be tolerated, if the same is promptly incorporated with the soil with the requisite precautions. (5) In places, especially in large cities, in which a speedy and regular removal for such agricultural use is not practicable, it is requisite that the refuse should be burnt or destroyed in furnaces. (6) The burning of the refuse disposes of the same by a method free from every sanitary objection, and is superior to all other systems of refuse-disposal, many of which can only be regarded as highly unsuitable for the purpose.

G. R. R.

Agricultural Use of House Refuse. Dr. Wilsing.

(Gesundheits-Ingenieur, Oct. 10, 1903, p. 449.)

It is stated that if it be assumed that the cost of the removal and transport of the domestic refuse must be undertaken by the municipal authority, its value, from the agricultural point of view, is greatly enhanced. Allowing for the charge (taken at one shilling per ton of refuse) for spreading, gathering and digging in to a greater depth those portions of the material which are unsuitable for the use of the farmer, he can well afford to pay 1*s.* 9*d.* per ton for the entire bulk, and he could therefore be charged 9*d.* per ton delivered. The approximate manurial value of one ton of ordinary house-refuse on the farm may range from 1*s.* 2*d.* to 4*s.* 2*d.*, according to Röhrecke. Some figures are given to show the cost of dealing with the refuse of the town of Bromberg. The expense of the collection is set down at £3,034 per annum, and the total bulk, taken at 166 loads of 2 cubic metres (70·62 cubic feet) each per week, amounts to 17,264 cubic metres, say in round figures 20,000 cubic metres per annum. The space needed each week for storing this quantity of refuse would be roughly 4,300 square feet, or an area approximately of 5 acres for one year, at a mean depth of 3 feet 3 inches. Making an allowance for the

two years of storage needed for preparation, and providing space for access and roadways, the area of land required for this bulk of material is assumed to be 9·29 acres. Sundry charges are estimated for turning over the heaps, adding lime and sand, and putting the compost on to the land. It is calculated that, all costs included, the 20,000 cubic metres would work out at £950. The expense of handling the refuse in this manner is compared with the cost of destructors and furnace-treatment, and it is stated that it is more profitable to make compost as described than to dispose of the refuse in any other way, in all those cases in which it is not possible to get rid of the material on the spot.

G. R. R.

Sanitary Aspect of Earth-burial. Dr. Matthes.

(Zeitschrift für Hygiene, vol. xliv., 1903, p. 439.)

The question of whether cemeteries are likely to cause injury to the health of those who may reside in their vicinity has already been considered and discussed from many different points of view; but the advocates of cremation have recently revived the opposition to the practice of earth-burial. Among the chief objections alleged against burial are the possible pollution of the subsoil-water caused by the products of putrefaction, and the dangers which might arise to public health by the dissemination in this way of micro-organisms known to be the active agents in the spread of various diseases. The author cites the opinions of previous writers who have investigated this subject, and briefly indicates the results of their experiments, with a description of the nature of the tests undertaken in each case. The main point to which attention is herein directed as a likely source of trouble is the fear that the subsoil water may become infected with the soluble substances due to the decomposition of the animal tissues of the decaying corpses, as among these are the highly poisonous matters included in the group of ptomaines and toxines. An account is then given of very numerous experiments conducted during a long series of years at the Hamburg Cemetery, where about 260,000 interments have taken place on a very restricted area, a plan of which is appended. The results of the chemical and bacteriological tests are set forth in numerous tables, and the Author states that during the period under observation, while the burials were taking place at the rate of 12,000 per annum, no augmentation was noticed in the amount of impurity present in the subsoil water. His investigations have proved, moreover, that in suitable soil, properly drained to a depth of not less than eighteen inches below the bottoms of the graves, no substances which from their chemical or bacteriological properties were likely to be injurious to health are to be found in the effluent from

the subsoil drains. The filtering effect, and the power of absorption possessed by the surrounding earth, suffice to eliminate all deleterious products.

G. R. R.

Electricity-Station of the Albbruck Paper-works in the Black Forest. F. ALLEMAN-GISI.

(Schweizerische Bauzeitung, vol. 42, 1903, p. 8.)

The paper-works at Albbruck is a branch of a large concern in Basle. There had been a charcoal ironworks on the site for many years, but in 1883 the present owners bought up the buildings and all the rights to the water-power. By means of a pipe line 4·15 feet diameter, a head of 164 feet was obtained which with a discharge of 70·6 cubic feet per second gave about 1,000 HP.

The river Alb flows from St. Blasien to the Rhine and lies in a deep ravine, and the Author gives details concerning its variable flow. At first, about 1890, the high-pressure turbines drove the machinery through shafting and belts, but in 1896 a second fall of 164 feet was brought into use and the power-house built at a distance of 2,180 yards from the paper works. Full details of the weirs, intakes and channels are given, with illustrations which show that the closed channel ends in a chamber provided with large grids to stop the stones and gravel. From this chamber a riveted iron tube with internal diameter of 4·26 feet descends to the turbine-house in which are fixed two turbines with two polyphase generators each of 500 HP. directly coupled to them. Both turbines run at 240 revolutions per minute, and the differential regulators are described and illustrated. There is also a small Francis turbine of 30 HP. for the exciter. The current is produced at 3,150 volts and 32 periods per second, and is then transmitted about 3,000 yards to the paper works through overhead wires. The current is transformed to 115 volts for lighting the power-house and adjoining buildings.

At the upper factory a 400-HP. asynchronous three-phase motor is installed and is fed direct at the high potential. It runs at 155 revolutions per minute, and its efficiency at full load is stated to be 93 per cent. A similar motor running at 210 revolutions per minute drives the lower factory, and both these motors work in parallel with turbines which assist to drive the shafting. There are also other motors, one of 60 HP. being used to drive a dynamo producing direct current at 115 volts for lighting. The plant works day and night and the output at full power 2,500 HP. is 25 tons of woodpulp and 16 tons of paper daily.

E. R. D.

Water-Power Electricity-Station at Avila, Spain.

(Revista de Obras públicas, 1903, p. 135.)

The town of Avila had established an electricity station for lighting, with two steam-engines each of 250 HP. The river Adaja flows near, and there are a number of small mills worked by water-power. The cost of coal was becoming so great that Mr. Ortuño, a civil engineer, was instructed to prepare designs for a water-power installation, and a fall about 3·1 miles down stream was to be used. Ths discharge of the river Adaja is very variable, as for 3 months there is scarcely any stream at all, and for 6 months about 176 cubic feet pass per second, while in a flood of 3 March, 1901, 6,000 cubic feet per second was gauged. The power which it was desired to obtain being 400 HP., and calculating upon 176 cubic feet per second, the necessary fall was 26·2 feet. The total cost of the water-power scheme has proved to be £17,390, and during last year a saving of more than 1,000 tons of coal, costing £2,250 has been effected; the capital laid-out therefore pays more than 10 per cent.

The works are illustrated, and the Author describes the calculations for the dam which differs in section from that obtained by the formulas used at Boix, Villar, or Krantz. The total height of the dam in the centre of the river is 41 feet, and in plan it forms part of a circle 492 feet radius. In periods of flood the weir will be submerged.

There are two turbines with horizontal axles each developing 200 HP., and coupled direct to monophase alternators developing 2,600 volts and 40 amperes at 250 revolutions per minute; each has an exciter giving 70 volts. The current is carried by an overhead line to the central station at Avila, and the loss between the turbine station and Avila at full load of 400 HP. is said to be 12 per cent. The whole work is stated to have been most successful, and Mr. Ortuño has become Vice-President of the Company. The receipts last year increased by £892.

E. R. D.

Soundness Tests of Portland Cement. W. P. Taylor.

(Engineering Record, August 15, 1903, p. 184.)

It is stated that three different forms of test have been devised for determining soundness in Portland cement: (1) Direct measurement of expansion; (2) normal tests; (3) accelerated tests. In America the plan of direct measurement has never been extensively used; in fact the old "lamp chimney" test is the only form of this determination ever practised, and the employment of this crude method is fast dying out. Tests of soundness are therefore limited to

the normal and accelerated tests on pats, cakes, and briquettes of neat cement. The latter tests are classified as: (1) The boiling test; (2) the steam test; (3) the hot-water test; (4) the flame test; (5) the kiln test; (6) tests under pressure of steam, hot air or hot water; (7) strength tests of briquettes kept under some of these conditions, compared with normal briquettes. Of these tests the first three are considered as being by far the most important. It is explained that in regular routine the accelerated test is made in boiling-water on cakes of cement in the form of a small egg, about 1 inch in long diameter—the method of conducting the test is described in detail. The causes which give rise to unsoundness are discussed and examined by reference to tables of experiments. The Author points out that an objection is made to tests of this type, owing to the great variance in the methods used, but he shows that the difference in the results of the various systems of testing in common use is less than it is generally supposed. Another matter which receives attention is the relation of the boiling tests to the other tests for soundness and strength, as made in the laboratory. In this connection the results of a considerable number of tests and tables of results are examined. It is asserted in conclusion that German chemists have decided that none of the so-called accelerated tests for constancy of volume are adapted to furnish a reliable and quick judgment in all cases concerning the practical applicability of a cement. The most important point established by the Author is that boiling means seasoning, and figures which are given respecting samples of cement, boiled after keeping them for a period, prove this fact conclusively. The right time to make the accelerated test of a cement is not at the beginning of the testing operation, when the briquettes are made, but at the conclusion. It is necessary also to decide whether the accelerated tests applicable to "dome kiln" products are safe for use with rotary kiln products. The Paper is illustrated with numerous photographs of specimens of testing.

G. R. R.

Concrete Re-enforcement. Julius Kahn.

(The Engineering Record, 17 October, 1903, p. 465.)

Reference is made to the increasing use of re-enforced concrete, and to the fact that vertical re-enforcement in the case of concrete beams is quite as essential as horizontal re-enforcement. In many instances the horizontal rods are surrounded by U-shaped stirrups of band-iron or twisted rods. The Author has made a number of tests on beams re-enforced with plain and deformed rods on the bottom, and without one exception all such beams, when tested to destruction under uniform loading, failed by vertical or longitudinal shear in the manner which has been already pointed out by Captain

Sewell. By the aid of a series of diagrams, attention is directed to the necessity for providing for vertical as well as horizontal re-enforcement, owing to the lines of principal stress, which are here indicated. It is insisted that the fundamental principles for the re-enforcement of beams are (1) That concrete should be re-enforced in a vertical plane as well as in a horizontal one. (2) The re-enforcement should be inclined to the vertical, preferably with varying upward curvature, approximating the line of principal tensile stress. (3) The metal should be distributed in proportion to the strains existing at any place. (4) The shear members should be rigidly connected to the horizontal re-enforcement steel. The general facts and arguments upon which these statements are based are dealt with in detail, and the Author illustrates by means of photographs the character of the failures of re-enforced beams of various kinds. Two of the beams tested had a span of 26 feet from centre to centre, and were made of concrete, composed of 1 part of cement to 5 parts of crushed stone, and 2 parts of sand, each beam was 16 inches deep by 12 inches at top and 9½ inches at bottom, and they were broken down with a distributed load of 110,000 lbs.; the beams breaking at the centre. Experiments were also conducted with concrete lintels, made on the system devised by the Author, and described by means of diagrams. A lintel 11 inches deep by 13 inches broad, with a span of 12 feet, re-enforced by a 12 inch by ¼-inch steel plate on bottom, with 1 inch by ¼-inch diagonal members, sustained uninjured a load of 3,400 lbs. per lineal foot, with a deflection of ¼ inch.

G. R. R.

German Normal Sand. GARY.

(Mitteilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1903, p. 2.)

Since February, 1901, the entire control of the supply of standard normal sand for cement-testing in Prussia has been entrusted to the Royal Testing Station at Charlottenburg, and, dating from that time, very numerous experiments have been instituted to ensure uniformity in the quality of this material. As far back as 1895, owing to doubts as to the permanence of the existing supply, comparative tests were undertaken of different samples of sand employed for testing purposes, and certain of the results then obtained were published. It was subsequently arranged to acquire a sand quarry at Freienwalde, to be used solely for the source of the future sand-supply, and definite regulations were drawn up for the sifting, washing and preparing of the sand, previous to its despatch in sealed bags, each containing 110 lbs. A contract was subsequently made with Messrs. Henneberg and Co., of Freienwalde, to ensure that all the conditions laid down as to the preparation of the sand were complied with. These conditions are set forth in

detail, and 10,296 sealed bags had been issued down to November, 1902. The Author deals with the questions involved in the production of this sand, and describes the standard perforated metal sieves to be employed in regulating the size of the component sand-grains; these sieves are illustrated by enlarged photographs. Numerous tables of experiments are given, and the results of using woven wire and pierced metal plates, with square or round holes, are contrasted. The investigations extend to the weights of the sand, the interstices between the sand-grains and the differences of the quality of sand from the various depths in the quarry. The behaviour of the Freienwalde normal sand, as compared with other descriptions of normal sand used for testing purposes, was likewise thoroughly investigated, and numerous analyses are given. The sand was likewise tested with various cements, and the tensile and compressive strengths, as ascertained by experiment, are set forth in tables. An account is given of the entire operation of preparing the standard sand at the quarries, including the washing in the machine contrived by Messrs. Paulsen & Goslich, which yields 141·2 cubic feet daily; the drying of the sand; the sifting by means of horizontal swinging sieves, capable of separating 2,204 lbs. per diem, with grains of the standard dimensions, viz.: capable of passing through square holes, each side of which is 0·034 inch, punched in brass plates and retained on similar plates having square holes with sides of 0·023 inch.

G. R. R.

Strength of Curved Beams. M. Tolle.

(Zeitschrift des Vereines deutscher Ingenieure, 1903, p. 884.)

In the ordinary theory of bending of straight beams a pure couple gives a neutral axis passing through the centre of gravity of the cross-section of the beam. If the beam is curved, however, the case is different. Suppose a curved beam to become further bent in such a manner that the neutral axis passes through the centre of gravity; it is evident that the fibres on the inside of the curve are more strained than those on the outside, and that the centre of stress will therefore not pass through the centre of gravity of the section. The Author sets himself the problem of finding by what external forces a curved beam will be strained in such a way that the cross-section will simply rotate about its centre of gravity without suffering a pure translation. These forces he finds to be equivalent to a force P^1 and couple M, the value of which are as follows:—

$$M = -\frac{\tau_1}{\tau} E r F^1$$

$$P^1 = \frac{\tau_1}{\tau} E F^1.$$

In these expressions the geometrical form of the short piece of the beam acted upon, is fixed by τ, r and F^1, τ being the angle between the end sections, r the radius of curvature of the centre line of the beam and F^1 is equal to

$$\Sigma f \frac{\eta}{r + \eta}$$

where f is the area of an elemental strip of the section parallel to the axis of curvature, η is the distance of this strip from the centre of gravity of the section. The strain is defined by χ_1, the angle through which one end of the short piece of the beam is turned. The above formulas show that in a curved beam, a force passing through the axis of curvature, and acting at right angles to a particular section, produces the same strain or kind of distortion in that section as does a force acting at an infinite distance—that is, a couple—in the case of a straight beam. The intensity of stress at any distance η from the central line of the beam is

$$\sigma = \frac{P^1}{F^1} \frac{\eta}{r + \eta}.$$

If these stresses are plotted as ordinates, with distances η for abscissas, the points obtained lie on an equilateral hyperbola.

The general case of any force and any couple acting on a particular section is easily reduced to the particular case of the force acting at the centre of curvature. If a pure couple acts alone, the stress is

$$\sigma = \frac{M}{r F^1} \times \frac{\eta}{r + \eta} + \frac{M}{r F},$$

and in this case the neutral line does not pass through the centre of gravity. The author gives a graphical method of obtaining the auxiliary area F^1. Calling F the area of the section of the beam, the ratio $\tau = F^1/F$ is a criterion of the value of the various sections; the larger it is the better use is made of the metal. Examples are then given of the application of the theoretical results to the calculation of stresses in crane hooks.

J. G.

Deformations and Ruptures of Iron and Soft Steels.

F. Osmond, C. Frémont, and G. Cartaud.

(Comptes Rendus, vol. cxxxviii., 1903, p. 851.)

In this short note the Authors classify the deformations observed in iron, distinguishing seven elementary forms. The peculiarity of iron is that it may possess three distinct structures, amorphous, cellular, and crystalline, at one and the same time, and the mechani-

cal properties belonging to each of these structures are different and even directly opposed. Iron, when cellular, is very plastic; when crystalline it is fragile, and as the two structures are found superposed in the same specimen, they give rise to results in apparent contradiction. The nature of a fracture in iron will depend on the particular structure which the process of manufacture has made to predominate, or which becomes predominant under the stresses applied. It is this dual character of iron which gives it its peculiar position among materials of construction, and explains the unforeseen fractures which sometimes occur in practice.

W. C. H.

The Measure of the Elastic Limit in Metals. C. Frémont.

(Bulletin de la Société pour l'Encouragement de l'Industrie Nationale, 30 September, 1903, p. 350.)

It is in some respects a controverted question whether there is really any such thing as an elastic limit, as physicists have proved by minute and delicate measurements that permanent deformations in metal may be brought about by very insignificant stresses. As a case in point, the author shows that in the steelyard of a testing machine capable of working up to 5 tons, the mere weight of the beam, or of the beam and scale-pan cause a slight deflection, from which the metal of the lever does not entirely recover when the beam is supported and the scale-pan is removed, and when the indicator should, in theory, go back to zero. In accordance with the mathematical definition, it might be deemed that the elastic limit had already been exceeded. As the load is increased, however, this set or deflection becomes gradually greater, until, with the full load of 5 tons, it is found that the lever-arm has acquired a permanent deflection corresponding to a load of 660 lbs., which, after the full charge has been applied for a number of times, indicates the zero-point of the metal in question. Attention is directed to the fact that the French Commission on Methods of Testing have formulated (1) a theoretical elastic limit, (2) a proportional elastic limit, and (3) an apparent elastic limit. Each of these definitions is considered and discussed in detail. By reference to numerous enlarged photographs of test-pieces, specially prepared with polished surfaces for microscopic examination, the Author explains certain changes in the superficial appearance due to the deformations caused by various tests, either in tension or in compression, and graphic diagrams are given to indicate the character of the stresses. In conclusion, the Author contrasts the three definitions of the elastic limit above mentioned, and shows that the so-called proportional elastic limit is very ill-defined, while the other terms are apt to be confusing. He states that there is, in fact, but one elastic limit for any sample of metal, which he calls

the "true elastic limit," and he shows how this limit may be determined. Other assumed limits which have been measured and described depend upon the circumstances under which they may have been obtained, and they are liable to grave errors. They are in effect subordinated to the appearance of partial deformations, the presence of which may be considered to be inevitable in practice, and which are due to purely accidental causes.

G. R. R.

Fire-Resisting Properties of Building Materials and Structures. V. PETRIN.

(Mitteilungen des Artillerie- und Genie-Wesens, 1903, p. 611.)

The Author discusses the fire-resisting properties of the various materials used in construction. Bricks of all kinds are highly refractory, whilst of two kinds of clay the one which is poorer in alumina, but richer in silica, is the more fire-resisting. Ordinary mortars disintegrate when heated, and hence walls are frequently overturned by the powerful jets of water which are turned on to them during the extinguishing of a fire.

The refractoriness of wood depends on its hardness and dryness, as well as on the percentage of resin contained, and the nature of the surface. Hard woods are less inflammable than soft woods, and wood which is embedded in sand, clay, or brick, resists the action of fire for a considerable time. Wood can never be made incombustible by treatment, but only difficultly ignitable.

The tensile strength of iron is reduced to about 90 per cent. at a temperature of 570° F., to about 70 per cent. at 930° F., and to 20 per cent. at 1,300° F. With 5 as the factor of safety, 1,300° F. is therefore the limit of stability.

The fire-resisting qualities of copper, zinc, asphalt, felt and plate glass, are discussed; Siemens' wire glass will stand temperatures of 2,370° F.; and Luxfer prisms are also very refractory.

Solid brick structures are incombustible, those made of magnesite and xylolith boards, etc., are not, and should not be used for chimneys or flues.

Armed concrete structures in which the iron rods are completely embedded in cement, are highly refractory. An experimental structure 12 feet square, with 15 feet walls, was constructed of Portland cement bricks, the ceiling (Weiss' system) being supported by an armed concrete pillar, and carrying a uniform load of 123 lbs. per square foot. The structure had been completed two months and the concrete used was 1 : 3 and 1 : 3·5. After a fire lasting for two hours, the centre pillar was found to be uninjured at the top and bottom, the middle portion only being slightly damaged, but never enough to lay bare the iron core. The

same was found to be the case with the ceiling. The temperature inside the armed concrete had reached 1,470° to 1,650° F. Structures of armed concrete may therefore be considered highly fire resisting.

The Author next discusses the precautions to be adopted when using corrugated iron ceilings, and unsupported brick pillars.

Wrought iron columns are weaker than cast-iron ones when heated, the stability of both being increased by embedding them in cement or asbestos.

Marble staircases readily crack when heated, and collapse, although the heat is insufficient to turn them into quick lime. In the remainder of the Paper, iron doors, roofs, trusses, and wooden pillars, are discussed.

L. F. G.

Apparatus for Determining the Velocity and Direction of Winds.

Austrian Imperial Military Committee for Technology.

(Mitteilungen des Artillerie- und Genie-Wesens, 1903, p. 553.)

The Author gives a description of the various anemometers used by the military committee, and mentions their defects. They may be divided into several classes, such as pressure, pendulum, suction, and rotary anemometers. Among pressure anemometers the simplest is Edward's, in which the wind pressure acting on a plate compresses a spring, which actuates a pointer plying over a scale graduated in velocities. Another example of this type of meter is Wellner's, in which the resisting force is provided by a weighted pendulum, the pressure exerted by the wind being transmitted by a parallelogram motion.

In Henault's pendulum anemometer, a hollow ball fixed to the end of a rod, pivotted on a horizontal axis, is displaced from the vertical by the wind pressure, the amount of displacement being measured. Venturi's principle is used in Bourdon's suction anemometer. Robinson's rotating cup anemometer is explained, and its action fully discussed.

In Casella's anemometer, a wheel with 8 vanes is set in rotation by the wind, and actuates a counter.

A vane for determining the direction and inclination of winds is also described.

The Paper is illustrated by diagrams of the various anemometers.

L. F. G.

Postal and Telegraphic Communication in the German Colonies. H. HERZOG.

(Archiv für Post und Telegraphie, 1903, p. 33, *et seq.*)

This is a series of articles dealing with the postal and telegraphic and telephone systems of communication with the colonies and foreign parts. The whole subject is too large to be dealt with in abstract, but details are given concerning the German colonies in Africa which adjoin the British colonies, and these are of some interest.

A map is given of German East Africa, which became a German possession in 1885, and the Author gives a detailed account of the postal facilities, and then deals with telegraphs and telephones. It appears that the first telegraphic connection was made in 1890 by the submarine cable Zanzibar-Bagamoyo-Dar-es-Salaam; this is 87 miles long. In December, 1891, the construction of the overland telegraph lines from Bagamoyo to Saadani and Pangani and Tanga was begun, and the Pagani river was crossed by a three-core cable laid in the river-bed. All the posts used were of Mannesmann steel tubes and coated with tar while hot. The wire used was steel, 4 millimetres in diameter. In spite of bad climatic conditions this line, 99 miles long, was constructed in 8 months. The line is worked partly by Morse code and partly by telephone, the latter being most useful for the Arabs and negroes talking the various dialects. In 1893, a further line, 156 miles long from Dar-es-Salaam-Mohorro-Kilwa, was begun, and Mannesmann poles again used, but in this case the lower 10 feet was protected by a jute wrapping impregnated with tar, and bronze wire 2 millimetres in diameter was used instead of iron, and found better for telephone service. Another line, 450 miles long, runs along the coast to Mikindani, and then a line direct from Dar-es-Salaam to the Tanganyika lake was begun in 1901, and is finished as far as Kilimatinde and will be completed to Tabora this year, and then carried to Ujiji on the lake. This line follows the caravan route. The same class of poles were used, and bronze wire of 3 millimetres in diameter. About 3,000 to 4,000 porters are used, and each pole of 21·3 feet long weighs 83·5 lbs., and those 28 feet long weigh 121 lbs. There is a telephone exchange in Dar-es-Salaam (the chief port) with 30 subscribers, and one at Bagamoyo with 2 subscribers. The map shows the relative positions of the British telegraph lines in Rhodesia, which adjoins.

E. R. D.

Use of Balloons with Auxiliary Air-Chambers.

H. DE LA VAULX.

(Comptes Rendus, vol. cxxxvii., 1903, p. 749.)

This Paper describes a method used by the Author for regulating and controlling the zone of navigation of a balloon filled with hydrogen, by fitting to it an air-chamber into which atmospheric air can be introduced at will, and again expelled when occasion demands. The suggestion of the use of such an auxiliary chamber was first made by Meusnier, who studied minutely the laws of equilibrium of an aerostat of variable volume; but his ideas were not put into practice until 1903, when experiments were made with two balloons almost at the same time, but each set independent of the other. One of these balloons, the "Djinn," which was prepared for its voyages by the Author, is described in this Paper, and a sketch is given showing the arrangements of the valves. On one trial the aeronauts crossed the English Channel from France during the night, and finally landed at Careham Hill in Yorkshire. Throughout the voyage they were able by using the air-chamber to choose their altitude, and so to take advantage of the most favourable currents. In addition, the economy effected in ballast was so great that, although the voyage lasted for 16 hours 40 minutes, the balloon landed with 475 lbs. of ballast on board, enough for another long voyage. On a second trial the Author fitted a cone to the top of the balloon to prevent rain-water gathering there and overloading the balloon. This arrangement was severely tested, as rain fell in torrents for the first two hours of the voyage, but the balloon kept itself steady, and no more ballast was lost than would have been lost from an ordinary balloon in good weather. At a later stage of the voyage snow fell heavily and loaded the balloon seriously, so that large quantities of ballast (over 12 cwts.) had to be thrown overboard. When this snow melted, the balloon, inflated with hydrogen, became dangerously light, so that without its special apparatus it would have soared to an altitude of 3 miles; but by filling the air-chamber the travellers never reached half that altitude, and were spared the discomforts and excessive cold experienced at such great heights. The balloon landed after 15 hours' travelling, and with nearly 6 cwts. of ballast still on board. The Author considers that by these trials the utility of these special appliances is fully proved.

W. C. H.

Repetition of Stress. F. Foster.

(Mechanical Engineers 10, pp. 704–706, November 22, and pp. 740–742, November 29, 1902. Paper read before the Owens College Engineering Society.)

The Author suggests a possible explanation of the phenomena caused by repetitions of stress in materials. If a bar receives by any mechanical process an elongation greater than that corresponding to the elastic limit under statical conditions, it will not return to its original form, having entered on the plastic state. Secondly, if a bar receives, in any mechanical way, a deformation equal to that causing fracture under statical conditions, then it will break. Also, if a bar be strained even within the elastic limit there is a time lag or hysteresis in its returning to its original form when the load is removed. If then, we have a variation of stress from load to no load, the second cycle begins before the extension due to lag on the first cycle has had time to disappear; this produces a greater residual extension at the beginning of the third cycle, and so on, until the elongation becomes equal to that due to the elastic limit, to the yield point, and finally to the statical elongation, and when this is reached the specimen will break. The diagram is intended to present qualitatively an idea of what is supposed to take place, the amount of lag being considerably exaggerated and the number of cycles shown in each part of the diagram having no quantitative signification. It is obvious that the greater the range of stress, the greater will be the lag per cycle of loading, and consequently the less the number of repetitions necessary to produce fracture. Increase of rapidity of repetition of the load would cause a diminution of the number of repetitions the specimen would stand before fracture, since the lag per cycle would be greater. It would be expected that of two bars having the same range of stress, the one having the higher mean value for the stress would require the less number of repetitions for fracture since it has less of the elongation in the elastic stage to make up by means of the added lags. The Author quotes figures and diagrams from the experimental results of Wöhler and others in support of his theory.

H. R. C.

Highly Superheated Steam. J. A. Ewing.

(Engineer, 95, pp. 186–187, Feb. 20, 1903.)

The Author refers to his test of an engine using highly superheated steam on the Schmidt system, in which the best consumption was the remarkable figure of 9 lbs. of steam per I.HP. hour, and inquires what may be the reason that an addition

of about one-fifth to the heat which the steam has already taken up from the boiler enables it to do 50 per cent. more work. The gain in thermodynamic efficiency is relatively small. The answer, apparently, is that by using highly superheated steam one escapes in great part the two chief sources of loss in the action of saturated steam; these are; (1) the loss due to alternate condensation and re-evaporation in the cylinder, and (2) the loss which arises through leakage at the valves, pistons, and sliding surfaces generally, especially direct through leakage from the steam to the exhaust side of a slide valve. The first of these losses is well known. With regard to the second, Callendar and Nicholson have shown that however tight a valve may be when standing still, it will leak while running; a film of water finding its way from the steam side to the exhaust between the sliding faces. The wetter the steam the more serious will this leakage become. A case is cited where the consumption of steam of a triple-expansion engine having piston valves was reduced by 42 per cent. for the same output by substituting steam superheated to 575° F. for saturated steam. Highly superheated steam enables comparatively small engines to compete in efficiency with those of the largest size, and permits of excellent results being obtained with two-cylinder expansion only; the engine referred to above was a two-cylinder compound of only 300 I.HP. To obtain the full advantage it is necessary that the steam should be superheated before each expansion; that is, the steam in the receiver which has become saturated or even wet by expansion in the previous cylinder must be again superheated before admission to the next cylinder; this may be done by the live steam on its way to the engine, as in the case referred to above.

H. R. C.

1,000-*HP.* *Gas-Engine.*

(Engineering, 74, pp. 302, 310, and 312, September 5, 1902.)

The engine was constructed by the Deutz Gas-Motor Works, and exhibited at Düsseldorf. The description is accompanied by three sectional drawings. The engine has four cylinders placed opposite each other, in pairs. The diameter of the cylinder is 33·07 inches, length of stroke 41·33 inches, and the engine makes 135 revolutions per minute. Each cylinder works on the four-cycle single-acting principle, and therefore the action of the engine is similar to that of a one-cylinder steam engine. The outside end of each cylinder at the lower part is provided with an exhaust valve, and at the top with an inlet valve. The latter is divided into two spaces by a plate, the top space being connected with the gas supply, and the lower one with the air supply. During the suction period the gases are forced several times through narrow vents—thus their

mixture is complete. The gas supply is regulated by two spring governors acting on tapered pins. The engine weighs 219 tons, including the 19-ton fly-wheel.

C. C.

500-*HP. Körting Gas-Engine and Blowing Cylinder.*

(Engineering, 74, p. 410, September 26, 1902.)

This engine was constructed by the Siegener Actien-Gesellschaft, of Siegen, and exhibited by them at Düsseldorf. There are five sectional drawings shown. The blowing cylinder, which is 69 inches in diameter, is provided with governed Corliss inlet valves and with Riedler-Stumpf delivery valves. These latter are closed at the end of each stroke by rubber buffers fitted to the piston. The engine-piston is about half the length of the cylinder in depth, and the exhaust ports are at the centre of the cylinder length, one set serving for both ends of the cylinder. The engine is provided with two pumps, one for scavenging purposes and the other furnishing the gas. The scavenging blast is followed directly by the charge of air and gas, which is compressed and fired in the usual way. There is thus an impulse every stroke. The governor regulates the supply by opening a bye-pass on the delivery from the gas pump. The compression is 120 lbs. per square inch, the pressure on firing may attain over 400 lbs. per square inch, the mean pressure being about 90 lbs. per square inch. The diameter of the engine cylinder is 26·87 inches, and the length of stroke 43·31 inches.

C. C.

Gas-Engine Test. R. Mathot.

(Power, N.Y., 23, pp. 64, 65, February, 1903.)

The Author gives the results, with specimen diagrams, of a test of a Charon gas-engine at Winterthur. The engine was a 23-B.HP. Otto cycle hit-and-miss governing, with electro-magnetic ignition. At full load with town gas of 598 B.Th.U. per cubic feet the B.HP was 22·9 cubic feet and the consumption 15·5 cubic feet as used, corresponding to 13·5 cubic feet at N.T.P., per B.HP. hour. With producer gas obtained from Belgian anthracite, the B.HP. was 20·2, and the fuel consumption 0·81 lbs. per B.HP.-hour.

H. R. C.

12-*HP. Spirit Locomotive.*

(Engineering, 74, p. 310, Sept. 5, 1902.)

This horse-drawn, portable engine is for driving threshing and other agricultural machines, and was exhibited at Düsseldorf. It weighs 4 tons. The length, without shaft for the team, is 11 feet 2 inches; width, 6 feet 3 inches; height, 7 feet 10½ inches; wheelbase, 6 feet 1 inch; distance between wheels, 4 feet 7 inches; diameter of front wheels, 2 feet 7½ inches; diameter of hind wheels, 3 feet 7½ inches; diameter of driving drum, 23⅝ inches; speed of driving drum, 420 revolutions per minute; width available for belting, 7⅛ inches. The motor is above the rear axle, and its action is transmitted from one of the fly-wheels to a counter-shaft placed over the front axle and fitted with two pulleys, from one of which the machine to be worked is driven by belt. The capacity of the spirit reservoir is sufficient for 10 hours' working.

C. C.

Auto-Benzine Fire-Engine.

(Engineering, 74, p. 310, Sept. 5, 1902.)

This was exhibited at Düsseldorf by the Deutz Gas-Motor Works. The motor is a 15 HP. engine placed over the rear axle. The motor crank-shaft is extended in front, and is provided with friction couplings for working the pump, the arrangement being such that, while travelling, the pump mechanism is disconnected and *vice versâ*. The motor is supplied with benzine by an atomizer, which consists of a receiver in which the benzine is maintained at a constant level by a ball-cock; a second receiver is provided with the rose and the air-pipe. During the suction stroke a current of air passes over the benzine and draws away a portion of it, which gets atomised in its travel. The fire engine has two travelling speeds, viz., 7 miles and 10 miles an hour. At a speed of 50 revolutions, the pump delivers 162 gallons per minute at a pressure of 85·3 lbs. to 99·5 lbs. per square inch. The capacity of the pump tank is 110 gallons.

C. C.

Tangential Water-wheels.

(Engineering, 75, pp. 401–404, March 27, 1903.)

In this article a summary is given of the development of the tangential water-wheel, with special reference to its application in water-power development on the Pacific coast of North America,

where they are most suitably employed, the head being generally great and the quantity of water comparatively small. The water supply there is heavily charged with sand, and the erosion of the buckets, although sensibly uniform, is very great. The fact that the bucket can be changed without the renewal of the whole wheel has caused this type of wheel to come much into use there. The article is fully illustrated, showing the different improvements made in the construction of the buckets, and contains some critical remarks in connection therewith; several of the governing devices used are also described in detail, and the results of a few tests made by independent experts, with similar wheels, are also given, but they do not seem to agree, the efficiencies obtained varying from 70 per cent. to over 90 per cent. No details are given as to how they are obtained. Wheels of this type have been supplied by Messrs. Abner Doble & Co., of San Francisco, to the Snoqualmie Falls Power Company. Several other plants are also mentioned where similar wheels are in successful use.

L. G.

Electrical Resistance of Bearings.

A. E. Kennelly and C. A. Adams.

(Electrical World and Engineer, 41, p. 231, Feb. 7, 1903.)

The oil in the bearing may cause a shaft to be insulated from the machine. The Authors tested a small machine, running at 1,800 revolutions per minute. When at rest the shaft was in good electrical contact with the bearing; at a speed of 100 revolutions per minute, however, the resistance between the shaft and the pedestals was 4·4 megohms, which amounted to 1,000 megohms per square centimetre of oil surface. The insulation is maintained under very considerable lateral pressure. With new dynamos, where the bearings are not worn, the insulation resistance is much smaller in amount. The insulation resistance in the case examined did not break down under 500 volts direct current or 1,670 alternating; but in the latter case it was very much reduced.

W. H. S.

Best Thickness of Transformer Stampings. H. Kamps.

(Elektrotechn. Zeitschr., 24, pp. 93–95, Feb., 5, 1903.)

On account of the appreciable thickness of the insulation between the stampings, the total iron loss, for a given total magnetic flux and total cross-section of core, does not decrease indefinitely as the thickness of the stampings is decreased, because,

although the eddy-current loss decreases steadily, the hysteresis loss increases on account of the increasing induction due to the reduced cross-section of iron. The Author deduces the following formula for the best thickness t of the stampings: $t = 79\sqrt[3]{\frac{\eta\delta}{n\,B_i^{0\cdot4}}}$, where η is Steinmetz's hysteretic coefficient, δ = thickness of insulation between stampings, η = frequency, and B_i is the ideal induction obtained by dividing the flux by the total cross-section of the core (no allowance being made for insulation). Assuming as average values $\eta = 0\cdot0015$, and $\delta = 0\cdot05$ millimetre, the Author arrives at the following Table of values of t:—

Frequency n =	25	50	50	100	100	140
Ideal induction B_i =	8,500	5,000	4,000	3,500	2,500	1,500
Actual induction B =	10,000	6,000	5,000	4,000	3,000	2,000
Best thickness t =	0·34	0·29	0·30	0·24	0·25	0·24

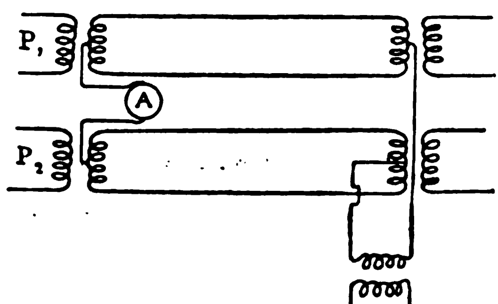
Taking next the special conditions relating to Continental practice, the Author also finds that the values oscillate about 0·3 millimetre, and he accordingly suggests that this should be adopted as the standard thickness for transformer sheets.

A. H.

Bedell System of Composite Transmission. A. S. McAllister.

(Elect. World and Engineer, 41, pp. 351–353, Feb. 28, 1903.)

This method of transmitting power is based on the independence of two alternating currents of different frequency, or of an alternating and a continuous current, when flowing along the same conductor. In the Bedell system a high-frequency single-phase



or a continuous current is superposed on a low-frequency two-phase system. The general principle of the arrangement will be readily understood from the accompanying sketch, in which P_1, P_2 are the primaries of a two-phase step-up transformer, connected to a two-phase generator of low frequency, intended for the supply

of power to motors. Connected to the middle points of the secondary windings is a high-frequency single-phase alternator or transformer A, which is intended for lighting circuits. Similar connections are adopted at the receiving end of the line. It is obvious that a continuous current might be used instead of the high-frequency single-phase one without in any way interfering with the two-phase system. Assuming that the total loss in the line and the amount of copper and line voltage are the same, the Bedell system is capable of transmitting 1⅛ times the power which a simple three-phase system could transmit. It has further the great advantage of independent regulation of pressures.

A. H.

Steam v. Water-Power for Electricity Works. A. Hecker.

(Elektrotechn. Zeitschr., 24, p. 131, Feb., 19, 1903.)

The Author has recently had under his notice a scheme for developing and utilizing water power by means of a dam erected across a valley, which would have involved a capital expenditure of M1,500,000 (£75,000) for the production of only 600 HP. He has therefore calculated what conditions of load would be required to render such a source of supply cheaper than steam power, assuming that coal would cost 2 pfennings per kilogram (20*s.* per ton) at the point of use, and that no running charges would be incurred when the water-power scheme had once been successfully inaugurated. He calculates that a capital expenditure of M400,000 (£20,000) would provide a steam plant to produce 600 HP., and taking interest at 4 per cent., and other capital charges, including depreciation, at between 4½ per cent. and 8½ per cent., he obtains the following comparative costs:—

—	Steam Power.			
HP.-hours per year . .	1,200,000	1,800,000	2,400,000	3,600,000
Cost per HP.-year in marks	93·70	112·61	131·48	169·22
—	Water Power.			
HP.-hours per year . .	1,200,000	1,800,000	2,400,000	3,600,000
Cost per HP.-year in marks	127·50	127·50	127·50	127·50

The water-power plant would therefore only prove more profitable than a steam-power plant where a load-factor of 60 per cent. or over could be obtained.

J. B. C. K.

Electric Power at Manchester Cotton-Mills, N.H.

(Electrical World and Engineer, 41, pp. 269-271, Feb. 14, 1903.)

Most of the power and lighting is carried out by polyphase current. The printing presses for the cotton prints are, however, driven by direct-current motors, each of them being supplied with current from a separate dynamo. The excitation of the magnets of the motors is kept constant, but the operator has the power of varying the excitation of his dynamo by means of a rheostat having fifty-one steps, the dynamos themselves being driven by induction motors. The speed of the printing press motors can therefore be varied from 1¼ revolutions per minute to 19 revolutions per minute by shifting the handle of the controlling rheostat over the fifty-one steps, each step increasing the speed on an average by about one-third of a revolution, and the voltage at the terminals of the motor armature is found to vary from 26 to 315.

W. H. S.

Mill Creek Power-Plant, Redlands, Cal. E. DURYEE.

(Engineering News, 49, pp. 133–134, Feb. 5, 1903.)

This installation is one of several owned by the Edison Electric Co. of Los Angeles, and is situated 12 miles from Redlands. Water is derived from the Mill Creek Cañon, 5 miles from the power-station, through a tunnel and short flume, fitted with a travelling screen to remove twigs, and sand-settling boxes. From the flume a pipe line takes the water 25,000 feet to a forebay; the pipes are of cement, in sections 2 feet long and 30 inches in diameter, made near the site of the line, and laid with a gradient of 0·2 per cent. This line passes through nineteen tunnels, aggregating 7,490 feet in length, and includes five inverted siphons to cross canons. The forebay stores sufficient water to carry the peak load for six hours. The pressure pipe line starts from the forebay, is 8,400 feet long, and has a fall of 1,906 feet. The lower pipes are 24 inches in diameter, and $\frac{5}{8}$ to $\frac{7}{8}$ inch in thickness. The power station is of concrete, with corrugated iron roofing, and forms an extension to a previously existing station, which contains two Pelton wheels coupled to 300-HP. three-phase alternators working at 11,000 volts. The new plant comprises four sets of 1,200 HP. each, working at 33,000 volts.

A. H. A.

Electric Power-Transmission in North California.

(Journal of Electricity, S.F., 12, pp. 231–238, Dec., 1902.)

The generating station of the Northern California Power Co. is at Volta, 30 miles from Redding, and is operated by water-power derived from springs, giving constant flow throughout the year. The water is brought 3,400 feet in an open canal to a reservoir, capable of running the plant for six hours. From this point the water is carried through pipes for 6,800 feet, most of the pipe being of steel, $\frac{5}{8}$ inch thick at the lower end, to withstand the head of 1,204 feet. A separate pipe brings water to the station with a head of 400 feet to work the auxiliaries. The generating plant consists of three 1,500-HP. Pelton wheels, coupled to 750-kilowatt three-phase Westinghouse alternators, all of which generate current at 500 volts. The nozzles of the water-wheels are controlled by Lombard governors. The main shafts are 9 inches in diameter and 10 feet long, and are carried on self-aligning bearings in large cast-iron bed-plates. The exciters are $21\frac{1}{2}$ kilowatt dynamos driven by small Pelton wheels mounted direct on their shafts. The transformer-room contains ten 350-kilowatt transformers, connected in groups of three delta fashion, with one spare; these raise the pressure to 22,000 volts on the line, but if necessary in future they can be joined up star-fashion to give a higher line pressure. The line consists of two three-phase circuits of Nos. 4 B. & S. bare copper, and runs to Redding, with branches to various places, the longest being 90 miles in length. Glass insulators are used, on wooden poles. At the sub-stations the pressure is reduced to 2,000 volts, three-phase or two-phase, for power and lighting service. The water power available can easily be increased to treble the present capacity at Volta. A 4,000 HP. plant is being installed at Cow Creek, 20 miles from Volta, consisting of two 1,500 kilowatt Westinghouse generators coupled to two pairs of Pelton wheels. The plant will be generally similar to the former, working with practically the same head. The exciters will be driven by induction motors and Pelton wheels alternately. The transmission lines will join the existing lines at too widely separated points. The illustrations accompanying the article relate to the hydraulic works only.

A. H. A.

Some Recent Water-Turbine Power-Plants. A. Steiger.

(Mechanical Engineer, 11, pp. 359–362, March 14, and pp. 391–394, March 21, 1903. Paper read before the Civil and Mechanical Engineers' Society, Feb. 5, 1903.)

In this paper the Author describes the characteristic features of some of the recently erected water-power plants here and abroad. The progress made during the last twenty years is very great.

Turbines are now made of units ranging up to 10,000 HP., as will be the case with the turbines to be erected on the Canadian side of Niagara Falls. There is a scheme in hand to erect turbines to develope 1,400 HP. under a fall of only 10 feet. The Author had to deal in this country with very irregular water supplies, affecting the fall considerably, but got successful results using the double-crowned Jonval turbines. To secure a good efficiency with the minimum supply, and to obtain a constant speed under varying falls, the subdivision of the parallel flow turbines into several compartments of different diameters was used. The quick acting of the governor, which is an essential condition in electric generating plants, has been achieved by the introduction of the hydraulic governor fully described in the paper. The Author describes several plants where turbines of the inward flow type are used, like those at Schafhausen; or at Sligo, on a tidal river, where the fall varied from 8 feet 6 inches to 6 feet 6 inches at neap tide, and 3 feet at spring tide. Mention is also made of the new turbines now erected at the new power-house at Niagara Falls, each being of 5,500 HP. The action of the hydraulic governor invented by Messrs. Escher, Wyss & Co. is shown on a diagram taken under actual operation, and the speed did not vary more than 3½ per cent., whether the load was suddenly increased or reduced, or entirely thrown off, and no "hunting" could be observed. The largest water-power plant in the British dominion is that erected at Cauveri Falls. The type of turbines used at the Lyons Electric Light and Power-generating Station combines the advantage of the parallel flow turbines with that of greater speed and better efficiency obtained from radial flow wheels, and is therefore suitable for low falls on large rivers. Several other plants are mentioned. The Author draws the conclusion that turbines can be made to give satisfactory results if the conditions under which they act are taken into proper consideration, and the right type accordingly selected. The low falls found in all parts of this country ought not to be overlooked as probable sources of power. The Author concludes his paper advocating a proper regulation of the water supplies, by building dams, which should retain part of the water coming from the hills, prevent to some extent the floods, which do a great deal of damage to low-lying country, and thereby secure a more regular flow of water for power purposes. The paper is fully illustrated.

L. G.

Columbia Electric Tramways.

(Street Railway Review, 13, pp. 61–65, Feb., 1903.)

The tramways comprise 14 miles of single track, operated on the overhead trolley system, with bracket and span suspension. The track is laid with 48-lb. T-rails, joined electrically with Columbia

bonds. Power is derived from the generating station of the Olympia Cotton Mills, which contains three McIntosh & Seymour engines coupled to General Electric three-phase alternators. The engines are rated at 1,600-2,000 HP. each, and are of the vertical compound type, with cylinders 20 inches and 48 inches in diameter and stroke 42 inches. The alternators have an output of 1,300 kilowatts each, at 40 cycles per second, 600 volts, 133 revolutions per minute. The switchboard is over 57 feet long, with 21 panels. The pressure is raised by transformers to 3,300 volts and transmitted 2 miles, by six No. 2 wires, to a sub-station near the centre of the city. From this point power is supplied for various purposes and in various ways; for traction the current is transformed and passed through rotary converters giving direct current at 550 volts. Each of the two converters is rated at 200 kilowatts. For constant pressure light and power, the three-phase current is split into two single-phase currents at the full voltage, and transformed down where it is used, or three-phase current is supplied and transformed to 550 volts for motors over 1 HP. For series arc lighting, 4 Brush arc dynamos are used, driven by synchronous motors and giving 5 amperes at 10,000 volts each. About 230 arcs and 11,000 incandescent lamps are in use. There are 30 cars of various types, fitted with "G.E. 1,000" motors. Details are given as to the mode of operating the system.

A. H. A.

Researches on Steel and Copper.

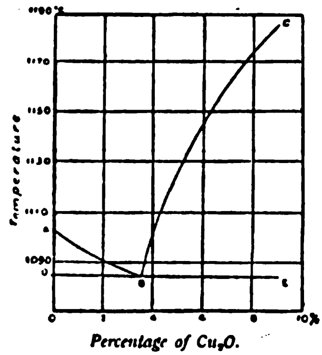
Reports from the Royal Mechanical and Technical Testing Institute of Charlottenburg.

E. Heyn.

(Metallographist, 6, pp. 39–64, Jan., 1903. Paper read before the International Association for testing Materials, Budapest Congress, 1901.)

(1) *Iron and Hydrogen.*—Mild steel heated in an atmosphere of hydrogen at 730° to 1,000° C. and then quenched in water becomes remarkably brittle, though its density and structure are perfectly normal, and the weight of hydrogen occluded does not exceed 0·0002 per cent. The effect slowly penetrates from the surface inwards, and can be completely removed by heating in air or nitrogen, and even by heating in atmosphere of hydrogen below 730° or by prolonged exposure to air at ordinary temperatures. It is pointed out that 0·028 per cent. of hydrogen in electrolytic iron renders it as hard as glass, and the brittleness observed by Ledebur in corroded steel was produced by only 0·002 per cent. of hydrogen. (2) *Copper and Hydrogen.*—Copper heated in hydrogen above 600° becomes excessively brittle, its density falls from 8·9 to 8·4, and its microscopic texture is also changed; this may be partly due

to reduction of cuprous oxide, but the hydrogen probably produces a specific effect on the metal. (3) *Copper and Oxygen.*—Copper and cuprous oxide are completely miscible when fused, but are mutually insoluble in the solid state. The eutectic-point lies about 20° below the melting-point of copper, and corresponds with the presence of 3·4 per cent. Cu_2O; alloys with less oxygen con-



tain copper crystals surrounded by eutectic, those containing more oxygen contain dendritic crystals of cuprous oxide surrounded by eutectic. The curve of freezing-points is shown in the figure. (4) *Permanent Deformations at Ordinary Temperatures.*—In a piece of the softest basic Martin steel 10 millimetres thick and bent over a dome of 10 millimetres, the average dimensions of the crystal particles in two directions when magnified 365 diametres were:—

	Millimetres.	Millimetres.
Stretched side, bent cold	6·6	13·5
Centre „ „ „	11·1	11·9
Compressed side „ „	12·6	8·3
Stretched „ bent at blue heat	11·3	11·4

Thus whilst bending at a high temperature leaves the particles equally developed; cold working produces a very marked distortion in the shape of the actual crystal-particles of which the metal is composed. The following table shows how the distortion of the particles, measured in three directions, produced in a piece of cold-worked copper gradually disappears on annealing:—

	Copper rich in Oxide.	Copper poor in Oxide.
Cold worked	26·4 : 28·5 : 46	27·4 : 35 : 46
Annealed at 480° C.	26·0 : 26·0 : 27	26·0 : 29 : 35
„ 660° C.	33·0 : 33·0 : 32	26·5 : 27 : 25

A higher temperature is necessary for annealing the copper poor on oxide.

T. M. L.

Overheating Mild Steel. E. HEYN.

(Iron and Steel Inst., Journ., pp. 3–39, Sept., 1902.)

The Author describes a number of experiments to determine the effect of overheating in producing brittleness in mild steel. He finds brittleness produced in low-carbon mild steel by long continued annealing at temperatures exceeding 1,000° C. Prolonged annealing for a fortnight or so at 700° to 890° reduces brittleness to minimum value, although leading to the formation of coarse ferrite grains. The brittleness can also be eliminated by half an hour's annealing at somewhat over 900°, but between this and 1,000° there is a limit beyond which brittleness increases with time, the more rapidly the more this limit is exceeded. Below 800°, five hours' annealing is insufficient to eliminate brittleness. Forging or rolling eliminates brittleness due to long-continued exposure to high temperature. The fracture, when overheated, is usually, but not invariably, coarse grained.

G. W. DE T.

Effect of Reheating on Overheated Steel. K. F. GORANSSON.

(Metallographist, 5, pp. 216–228, July, 1902.)

It is known that steel which has become coarse through overheating can be made fine by reheating to a certain temperature. The Author describes experiments leading to the conclusions that the destruction of the coarse net-work of cementite is caused by solution of its carbon in the martensite, and that the net-work surrounding the new grains is formed by the expulsion of cementite from the martensite as it is being cooled. According to this theory, the steel should be heated to a sufficiently high temperature to ensure complete solution of the cementite. Some comments by H. M. Howe are given as an appendix to the paper.

G. W. DE T.

Elasticity of Nickel Steels. C. E. GUILLAUME.

(Comptes Rendus, 136, pp. 498–500, Feb. 23, 1903.)

Observations are made at different temperatures upon a chronometer provided with a spiral of the alloy to be studied, acting as balance spring. Knowing the dilatation of the spring and the rate of the chronometer, the formula connecting thermal variation of modulus of elasticity with temperature is obtained. A table of values of the elastic co-efficients for different alloys is given.

J. W. P.

Changes in Nickel Steels. C. E. GUILLAUME.

(Comptes Rendus, 136, pp. 356–358, Feb. 9, 1903.)

Bars of the alloys are kept for long periods at steady temperatures, and the variations of length, due to the after-effect of a previous heating, are observed. Alloys of different kinds are considered, and their suitability for standards of length commented upon. The distinction (previously pointed out) between reversible and irreversible alloys is again remarked in these experiments.

J. W. P.

Variation of Wind-Velocity in the Vertical. A. EGNELL.

(Comptes Rendus, 136, pp. 358–361, Feb. 9, 1903.)

The wind velocity increases rapidly from the surface layers up to a height of about 300 metres, (984 feet) where the surface-friction becomes negligible. Multiplying the wind velocity, as deduced from cloud observations at Trappes, by $b/760$, and without making any allowance for the temperature diminution in the upper strata, the author arrives at the conclusion that the quantity of air displaced is constant for all elevations between 300 metres and 12 kilometres ($7\frac{1}{2}$ miles), or that the wind velocity varies inversely as the density of the air. This law seems to agree with the observations made at Upsala, Bossekop, Blue Hill and Washington (all within the temperate zone), but not for Manila (in the tropics), where the wind velocity ($7\frac{1}{2}$ miles), decreases with increasing altitude.

H. B.

Dilatation of Tempered Steel. G. CHARPY and L. GRENET.

(Comptes Rendus, 136, pp. 92–94, Jan. 12, 1903.)

The authors have examined the effect of tempering on the dilatation of steel. Small specimens were used, so that in tempering they could be chilled very rapidly: the results hold only for such rapid chilling, From the data it appears that (1) in the case of soft steels (0·5 per cent, of C), tempering does not affect the coefficient of dilatation, whatever be the temperature to which the steel is heated for purposes of tempering. (2) In the case of medium steels (0·6 to 1 per cent. of C), a similar result is obtained where oil is used. In the case of water, however, the temperature to which the steel is heated must not exceed 900°, otherwise the curve of dilatation shows a sharp change, corresponding to a contraction of about 0·1 per cent. between 250° and 350°. (3) A

similar result to (2) holds for high carbon steels, except that tempering by heating above 900° and chilling in water leads to a dilatation curve showing two contractions (at about 150° and 300°).

D. H. J.

Constancy of Manganin Low-Resistance Standards in Practical Use. ST. LINDECK.

(Zeitschr. Instrumentenk., 23, pp. 1–6, Jan., 1903. Communication from the Physikalisch-Technische Reichsanstalt.)

Thirty-one of the resistances which were standardised at the Reichsanstalt in the years 1897–98 and have since been in use by different firms have been again standardised, and the variations are given in the following table:—

Value of the Resistance in Ohms.	The Observed Alteration amounted to				
	0·00 – 0·01	0·01 – 0·02	0·02 – 0·05	0·05 – 0·10	> 0·10 per Cent.
0·01	in 5	3	2	..	1 resistance
0·001	„ 7	1	2	1	1 „
0·0001	„ 3	2	1	2	..
Sum .	15	6	5	3	2 resistances

Of the 31 examined, 26 have remained constant for all practical purposes, the alteration being under 0·05 per cent. The two resistances in the last column had undergone physical changes which were apparent to the eye. One had been in daily use for four years and had a coating of slime from the petroleum which had been used; the other had a deep brown colour, but no information was obtainable as to how this colouration was caused.

J. B. H.

Barlow's Wheel. E. CARVALLO.

(Journ. de Physique, 2, pp. 122–125, Feb. 19, 1903.)

The usual instrument requires a current of at least 7 amperes and a potential difference of 0·4 volt between the axle and rim of the wheel. By suitable arrangements, and with an electro-magnet in place of a permanent magnet, a wheel can be easily made to revolve thirty to sixty times a minute by the current given by an iron-constantan thermo-couple heated to cherry-redness (current 1·5 ampere electromotive force 0·03 volt, magnetic field 3,000 gauss). The slight action between the mercury and the nickled

surfaces used causes the wheel to stop after about a quarter of an hour, but with cleaning of the nickel and renewal of the mercury, the revolution recommences.

R. E. B.

Recording Galvanometer and Rotating Contact-Maker.

J. CARPENTIER.

(Soc. Franç. Phys., Séances, 2, pp. 69–72, 1903.)

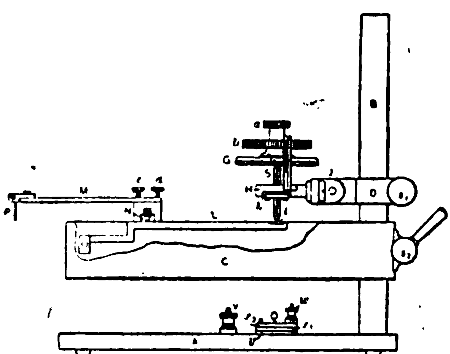
The galvanometer is of the Deprez-d'Arsonval type, the moving coil carrying two pointers placed horizontally. One of the pointers enables the current to be read, and the other makes a trace, by means of the recording pen, on a sheet of paper which is moved by clockwork, and the speed of which can be varied between wide limits. The rotating contact maker is an amplification of that of Joubert. A synchronous motor operates a discharge key at suitable intervals. The instrument was shown in operation, making a trace of an alternating-current wave.

A. R.

Electric Micrometer for Laboratory Use. P. E. SHAW.

(Physical Review, vol. xvi., pp. 140–157, March, 1903.)

This paper describes a simplified form of Shaw's electric Micrometer for workshop or laboratory use. A horizontal base plate A (see Fig.) has a vertical pillar B screwed to it. On this and



clamped by the screw S runs the sleeve D, which carries the measuring screw S and the nut H, there being between H and D a universal joint J. The micrometer head *a*, *b* G S H can be placed

in any position. The micrometer screw S has a pitch of $\frac{1}{2}$ millimetre (0·020 inch), and there is a graduated disk G, having 500 divisions on it, so that each division corresponds to a movement of the micrometer screw point t of $\frac{1}{1000}$ millimetre. Each division can be subdivided by the eye into 4 parts, so that $\frac{1}{4000}$ millimetre can be measured. The milled heads a and b are the coarse and fine adjustments of S. The material to be measured is placed between two steel plates having perfectly true faces, mounted on the base plate but insulated therefrom. The electric circuit is from the battery through a suitable resistance and telephone receiver to the base plate, thence to the micrometer screw. Directly this touches the top plate the electric circuit is complete and the telephone sounds. Two measurements are taken, one with the material in and one without. The difference is the desired measurement. The range of the instrument is from $\frac{1}{1000}$ millimetre (μ) to 40,000 μ or more, to an accuracy of $\frac{1}{2}$ μ. No appreciable pressure is necessary, as in other measuring instruments, *e.g.*, the micrometer gauge Whitworth measuring machine, and the micrometer screw S is made to work in its nuts without back-lash. The application of the method to the measurement of thin metal plates, wires, non-conducting materials, Young's modulus, torsion of a rod, thermal expansion of a tube, microscopic measurement, and the direct measurement of wave-length is described in detail.

A. C. H.

Effect of Temperature on Permanent Magnets. H. B. Loomis.

(Amer. Journ. Sci., 15, pp. 179–194, March, 1903.)

I. Experiments are made first to discover the effect of temperature on the magnetic moment of magnets of the same cross-section (0·159 centimetre) but of different lengths. A magnet was suspended by a long silk fibre in a double-walled box whose temperature was either 11° C. or 99° C.; vibrations were counted, and hence M found from the well known expression $M = \frac{4K\pi^2}{T^2 H}$. Correction was made of K and of the length of the magnet for change in temperature. The proportional change in temperature $\frac{M_{11} - M_{99}}{M_{11}}$ was 0·056 for a magnet of length 21·5 centimetres ($8\frac{1}{2}$ inches) and increased to 0·22 as the length decreased to 5·4 centimetres ($2\frac{1}{8}$ inches). It was observed that $\frac{M_{11} - M_{99}}{M_{11}}$ decreases as intensity of magnetisation increases.

II. The second part of the paper deals with the effect of temperature on the distribution of magnetism in a magnet. Two magnets are dealt with at once, each in its own heating chamber; each is encircled by an exploring coil, the two coils being connected

by a long brass rod, which passes outside the heating chambers so that the positions of the coils can be changed by hand. The coils are joined to a ballistic galvanometer, which is standardised regularly by an earth inductor. Then, both magnets being at 14° C., the throws are observed as the coils are moved in conjunction from end to end. The action of the two coils is of course made differential. If next one magnet is maintained at 14° C. and the other at 99° C., the movement of the coils will produce a set of throws different from the previous set if the distribution of magnetism has changed in the heated magnet. Curves for the results obtained are given in the paper and the results discussed.

P. E. S.

Nature of Accidents and Death due to Industrial Electrical Currents. F. Battelli.

(Archives d'El. Médicale, 10, pp. 777–799, Dec., 1902.)

Experiments on animals prove that electric currents cause death in two ways, according to the voltage. When an alternating voltage of 1,200 or more is applied between the head and legs of animals, death ensues from inhibition of the respiratory centre. The blood pressure rises enormously through the tetanisation of the muscles, while the heart-action continues. Life may be restored by artificial respiration. Voltages not exceeding 120, cause paralysis of the heart, while the nervous centres are but little affected, and breathing continues for some time. The paralysis is accompanied by a disordered non-rhythmic contraction. On breaking the circuit, the auricles assume their normal rhythm, but the ventricles in dogs, and usually in guinea-pigs, do not recover. In certain animals, however—for example, rabbits and rats—this form of paralysis of the heart only continues during the passage of the current. These animals recover if the current is interrupted in time, while dogs always, and guineas-pigs usually, die. Pressures of 240 volts to 600 volts produce in dogs both arrest of respiration and paralysis of the heart. When the heart of a dog has been paralysed by a current of low voltage, it can be made to beat again by the application to the actual wall of the organ of a current of high voltage, and in this way life may be restored. The nervous phenomena produced are chiefly arrest of respiration, tonic or clonic convulsions, and loss of consciousness. They vary with the voltage, with the point of application of the electrodes, and with the size of the animal, being most marked when the voltage is high, when the electrodes are placed close to the nervous centres, and when the animal is small. Continuous currents act in much the same way as alternating ones, but, with the former, a voltage four or five times greater is required to paralyse the heart. The effect of continuous currents on the

nervous system, however, is more marked than that of the alternating and is developed more rapdily. The frequency of alternating currents is an important factor. About 150 ∽ is the most fatal. Above this the minimum voltage required to cause death increases rapidly, *e.g.*, 15 volts at 150 ∽ will kill a dog with the electrodes in the mouth and rectum; 200 ∽ requires 35 volts, and 1,700 ∽ 400 volts. Between 30 ∽ and 150 ∽ the difference is not great. The duration of the current, other conditions being equal, naturally influences the effects produced. Autopsies on animals and human beings killed by electricity do not show any very characteristic conditions, excepting skin-burns.

The Author considers that sudden death is due exclusively to paralysis of the heart of the same nature as that which he observed in animals, and he thinks that this condition persists after the current has ceased to flow through the body, as it does in the dog. If the heart is thus paralysed, no practical method of treatment can prevent the fatal issue. Industrial alternating currents of frequencies varying from 30 to 150 may be said to become dangerous at 400 volts to 500 volts, and continuous currents at 1,500 volts.

H. W. P. Y.

Experimental Researches on Drawn Steel. J. R. Ashworth.

(Roy. Soc., Phil. Trans., 201, pp. 1–35, March 11, 1903. Roy. Soc., Proc., 70, pp. 27–30, May 12, 1902.)

This paper is divided into two parts. The first gives a complete investigation of the temperature coefficient of a magnet. The experiments were mostly made on twelve samples of pianoforte steel wire, representing every stage in the process of drawing from the rolled rod, through annealing and tempering, to the fine-drawn wire. In part two, the twelve samples were examined for resistivity and its temperature coefficient; for Young's modulus and its temperature coefficient, and for density. For the results obtained reference must be made to the original paper.

E. C. R.

Friction in the Bearings of High-Speed Machines. O. Lasche.

(Zeitschr. Vereines Deutsch. Ing., 46, pp. 1881–1890, Dec. 13; 1932–1938, Dec. 20; and pp. 1961–1971, Dec. 27, 1902.)

Experiments were undertaken by the Allgemeine Elektrizitäts Gesellschaft in view of the high-speed traction work which they had in hand, and of turbine-driven machines which they were constructing. The Author gives a short summary of work done by Thurston, Tower, and Woodbury between 1873 and 1884, but

none of these observers carried their experiments beyond a rubbing speed at the journal surface of 6 metres (20 feet) a second, or a temperature in the bearings of more than 90° C. Most of the work was done at much lower limits. In the following summary of the Author's paper, p is the specific pressure on the bearing in kilogram per square centimetre, v the velocity of rubbing at the journal surface in metres per second, t the temperature in the bearing in degrees Centigrade, and μ is the coefficient of friction. The apparatus used is first described together with the methods of observation and measurement. The effect of p on μ is first determined, t varying between 50 and 100, and p between 1 and 15. The coefficient of friction decreases with increasing pressures in the bearings. Taking $t = 50$, and $v = 10$, the results roughly approximate to the fact that $p\mu = 0 \cdot 04$, for journals of steel, nickel steel, or wrought iron running in bearings of bronze, white metal, or mercury alloy. Any increase of bearing surface, by decreasing p tends to increase μ, supposing, of course, that the speed of rubbing remains as before. It follows from this, that with a given load and a given velocity of rubbing, it is a disadvantage, from the point of view of friction, to have long bearings and journals of large diameter. With p constant, Thurston found $\sqrt[5]{v}$ proportional to μ up to $v = 6$. Bach found from an examination of Tower's experiments, that μ was proportional to $\sqrt{v}$ up to $v = 2 \cdot 4$, this being really in agreement with Thurston, as shown by Stribeck. The Author's experiments show that for values of v greater than 10, μ is nearly constant, and with $p = 6 \cdot 5$, and $t = 50$, μ is $0 \cdot 00615$, with bearings and journals as before. With increasing temperatures, μ decreases, and between temperatures of 40° and 100° C., the product μt is practically constant. With $p = 6 \cdot 5$, $\mu t = 0 \cdot 3$; therefore the equation $pt\mu = 2$ is true for all values of p beween 1 and 15, of t between 30 and 100, and of v between 1 and 20. Journals were constructed of various materials, viz., nickel steel, Siemens-Martin steel, and wrought iron; but results were not much affected by these variations. With $p = 6 \cdot 5$, $\mu = 0 \cdot 008$ for steel and wrought iron, and $0 \cdot 006$ for nickel steel, with $v = 10$, and $t = 50$. The hardness of the surface has therefore little to do with it; wrought iron lay between nickel steel and Seimens-Martin steel in the results; and microscopical examination showed that the polish of the nickel steel was slightly rougher than that of the others. Bearings were made lined with bronze, white metal and mercury alloy; but here again the difference in the readings was not very marked. The choice of metals for bearings depends largely on the other considerations, and in the case of machines with heavy flywheels or of those which should not be stopped suddenly, white metal is to be preferred. Different lubricants were employed, viz., imperial oil, rape oil, and sperm oil. There was little difference observed between these oils, when once full speed was reached; but on starting the machine, the friction was very different, sperm oil being the best, and imperial oil the worst. The physical properties of the oils themselves at high temperatures

are, however, more important. Whether the lubricant is conveyed by pressure to the bearings, or by rings or other means, must depend on the circumstances of the case under consideration. The important thing is to know under what conditions the oil actually reaches the bearing surfaces, and the amount of oil which is distributed by the ring, or other systems, under known conditions of running. Experiments were carried out to find how much oil was conveyed under given circumstances by the ordinary ring system of lubrication, the oil being collected and drained away as it passed through the bearings. It was found that the amount increased with the speed up to about 2,500 revolutions per minute. The amounts also varied very considerably with the direction of rotation, and the quantities which flowed out of a bearing at the two ends were very different. The play allowed in the bearings has great influence on the friction. With a shaft 260 millimetres ($10\frac{1}{4}$ inches) in diameter, and $v=10$, $t=50$, the friction decreases rapidily up to about $1\cdot5$ millimetres clearance, with $p=1$; with values of p between 10 and 15, the friction decreases steadily but more slowly up to $2\cdot5$ millimetres clearance. With a given clearance, the friction increases at first with p, but becomes nearly constant after p reaches the value 7. Mention is made of a specially constructed bearing which consists of three bearings, one within the other, the whole being supplied with oil under pressure. It was made for a 400-kilowatt turbine, running at 3,000 revolutions per minutes, and has a total play of $0\cdot35$ millimetres, with a shaft 110 millimetres ($4\frac{1}{3}$ inches) in diameter, the temperature of the bearing being 45° C. above that of the atmosphere when fed with $7\cdot5$ litres ($13\cdot2$ pints) of oil per minute under a pressure of 5 atmospheres. A series of experiments was also undertaken to determine the dissipation by radiation and the temperature rise in the bearings with different forms of construction and with different dimensions of bearings. These were carried out, partly by filling the bearings with oil, and passing current through a spiral immersed in the oil, and taking readings when a state of equilibrium was reached; and partly by observations on running machines, oil being supplied at different temperatures and pressures. For particulars and results of these experiments, the original articles should be consulted. Observations were made in which the temperature of the bearings rose to 132° C.; at about 125° the oil appeared to lose some of its lubricating properties, and the friction increased accordingly. Some bearings were also constructed in which 32 holes were bored to receive thermometers, and readings were taken which are graphically reproduced. The articles contain a large number of curves, many of which are arranged on the trilinear co-ordinate system, showing the relations between three variables.

W. H. S.

Operation of Steam Turbines with highly Superheated Steam.

E. Lewicki.

(Zeitschr. Vereines Deutsch. Ing., 47, pp. 441–447, March 28; 491–487, April 4; and pp. 525–530, April 11, 1903.)

The writer describes some very elaborate investigations which he made upon a de Laval turbine, and sets forth the conclusions at which he has arrived. The machine employed in the experiments has a speed at the turbine shaft of 20,000 revolutions per minute, this being reduced by gearing to 2,000 revolutions per minute. It has a normal capacity of 30 brake HP. when operated at a pressure of 7 kilograms per square centimetre (7 atmospheres), and non-condensing. The peripheral speed of the 200-millimetres (7·8 inches) diameter turbine wheel is 209 metres (686 feet) per second. The writer comments on the custom of expressing the steam consumption in kilograms per horse-power-hour at a given degree of superheat, without consideration of the extra expenditure of energy required to bring the steam to this degree of superheat, and recommends instead that the consumption should be expressed in heat units. The de Laval turbine is the only one at present capable of withstanding the highest degree of superheat. The experiments were carried up to 500° C., and no insuperable difficulty was encountered. The bearings are inaccessible to the hot steam and run cool, nor can the lubricating oil gain access to the steam, which may be again directly employed for boiler feed. For the bronze nozzles and valves, others of iron had, however, to be substituted on account of the smaller coefficient of expansion of iron. Wear of the turbine blades is found to be altogether absent with highly superheated steam. The strength of steel is known to be unaffected up to 300° C., and the turbine wheel, with the highest degree of superheat, will always cool the steam down to this value. By employing a regenerator, the use of a very high degree of superheat permits of high economy with low steam pressure. Tests with steam at 500° C. and a pressure of 7 kilograms per square centimetre showed an increased economy (in thermal units) of 16 per cent. In these tests the exhaust steam still had a temperature of 343° C. Enough of the corresponding heat energy may still be recovered to bring the increase of economy for 16 per cent. up to 30 per cent. This regenerative process, by which a large part of the energy in the exhaust steam is employed in raising fresh steam, is described in the article, though it has not yet been fully carried out in practice. The method permits of obtaining the advantages incident to the use of low steam pressure for de Laval turbines. Running condensing, the percentage economy in heat units is less; nevertheless, with single-stage turbines, the increased economy is enough to constitute a decided advantage. The tests showed that the friction of the turbine wheel decreases very rapidly indeed with increase in superheat; hence the mechanical efficiency increases.

The writer considers that, with a pressure of only 1·5 kilograms per square centimetre, a good vacuum, and superheat to 550° or 600° C., the steam turbine of this type, with regenerator, will, in fuel consumption, equal the best piston engine running condensing and with saturated steam. In the interests of minimum friction and minimum radiation from the turbine casing, the turbine wheel diameter should be small and its speed high, and gear reduction should be used. Worm gearing of 95 per cent. efficiency is already obtainable, and this loss is much less than is incurred in other ways in avoiding the use of gearing by means of multiple-stage low-speed turbines. The writer is sceptical as to the success of the use of steam at 300° C. in the new Parsons-Brown-Boveri multiple-stage turbines at Frankfurt-am-Main. He proposed to make experiments on a double or compound turbine in which the first shall operate with steam at high pressure and moderate superheat (350° C.), after which the steam shall be raised to 500° C. or 600° C. and admitted to the low-pressure turbine. For this purpose he will use a high-pressure boiler, and two superheaters to give these respective temperatures. He also proposes a plan whereby a high-pressure, low speed piston engine exhausts into an intermediate receiver which serves as supply for a low-pressure condensing turbine. By such an arrangement it would be permissible in the receiver to bring the steam to a degree of superheat far higher than would be compatible with the properties of the piston engine. The low-speed piston engine would drive a transmission directly, while the energy of the high-speed turbine would be employed in driving a dynamo.

H. M. H.

Superheating in Central Station Engines. A. Vanderstegen.

(Soc. Belge Elect., Bull., 20, pp. 93–118; Discussion, pp. 119–124, March, 1903.)

After a general review of the subject in its modern aspect, dating from the Mulhouse school of Hirn and his pupils, the Author discusses some tests with an economical type of engine in order to obtain the laws applying to this type. The tests were carried out by Schröter, of Munich, and Vinçotte, of the Association for the Inspection of Boilers, their results being elaborated in a series of tables and diagrams which accompany the Paper. The tests were carried out by each experimenter independently, with a compound engine, having high-pressure cylinder 325 millimetres diameter, low-pressure cylinder 560 millimetres diameter, stroke 850 millimetres, and 127 revolutions per minute. A direct-coupled dynamo was employed, the current from which was absorbed by liquid resistances, so that the output was maintained constant for each test; the boiler was a De Naeyer multitubular, and the Maiche superheated was independently fired so that the temperature of superheat could be controlled. Every precaution

was taken to have correctly calibrated instruments and correct weights and temperatures. The total error was brought down to 2 per cent. Three series of tests were made by Schröter: the first, to determine the consumption of saturated steam for different powers; the second, with superheated steam of 300° C. superheat under the same conditions; and the third, to ascertain the consumption of steam superheated to different temperatures up to 350° C. for a normal load. Vincotte's series was more varied, being made in duplicate, one with the high-pressure cylinder steam-jacketed and one without; and they measured the consumption of steam for different loads at temperatures ranging up to 350° C. above saturation. For normal load the temperatures were carried to 375° and 400°. The diagrams, given in three plates, embody Vincotte's results and they exhibit the concordance of the different tests and the absence of sensible errors. Schröter obtained, with the small compound engine of 250 I.HP., with saturated steam, a minimum consumption of 5·5 kilograms (12 pounds) per I.HP.-hour, and with superheated steam a consumption as low as has been obtained with triple-expansion engines of 3,000 HP. at equivalent temperatures. As deduced from the tables the relative economy in weight of steam due to superheating amounts to about 20 per cent. at 300° and 30 per cent. at 350°. But these are only apparent economies, because the consumption of heat must be considered, and superheated steam represents more heat than saturated steam. The real economy due to superheating, as well as the reduction of the consumption of steam, is proportional to the degree of superheat or the temperature of steam entering the cylinder above that of saturated steam. This is the Author's statement of the law deduced from the diagrams, and it holds good up to 350°, but above that point the economy is diminished, and difficulties of lubrication, and from expansion of the metal, increase. The real economy will be about 9 per cent. or 10 per cent. with a temperature of 300° C., and about 14 per cent. or 15 per cent. with 350 C. superheat in the case of an engine economical with saturated steam—more in the case of defective types. The Author investigated the most economical load corresponding to an extended rate of expansion, this rate being the same for all temperatures used. The most favourable expansion was found to be about 15 times the volume admitted at 9 atmospheres, and the range lying between 10 per cent. and 25 per cent. of the admission was found to be equally economical. This is important, in view of the varying demands of central stations, as showing that the consumption of steam may be economical within close limits as the load varies between half and full load. This gives the steam engine an advantage over turbines and gas engines. The following points are dealt with, viz.: The influence of speed of rotation on steam consumption, accelerated speed having the advantage of reducing dimensions and radiation; the influence of steam jackets, these being found to be unnecessary for the HP. cylinder with 250° of superheat, and for the LP. cylinder with 350° superheat;

the consumption of heat and the best temperature to employ; the regulation of temperature; the section and covering of steam pipes and the velocity of the steam in them; and the use of bronze and other substances affected by high pressure. In the discussion, Léon Gerard referred to the economy obtained at the Berlin station of Oberspree, which was less than that of the Author. He also raised questions as to the velocity of superheated steam and the fuel economy of superheater. In all installations it is necessary to observe closely the temperatures and prevent sudden variations. The Author, in reply, stated that according to Datterer, Director of the Berliner Electricitäts Werke, the economy due to superheating was about 8 per cent. to 9 per cent., the engines not being suitable for use with saturated steam, the sections of piping being too small and no jackets existing. About 25 per cent. of the velocity of saturated steam was the increase of velocity required. Replying to Malengraux, the normal pressure in the tests was 9 atmospheres, but some experiments were made also at 7 atmospheres, with similar results. Answering W. Kummer, the use of superheaters simply reduced the weights of coal and water used, but not the weights of engine for a given power.

F. J. R.

Efficiency of Non-Conducting Coverings. S. H. Davies.

(Soc. Chem. Ind., Journ., 22, pp. 198–200; Discussion, p. 200, Feb. 25, 1903.)

The Author gives the results of tests of various materials which may be used for covering the walls of cold chambers, lager-beer cellars, fermenting rooms, and the like, or for insulating brine pipes against heat transmission, the highest temperature employed being that of boiling water, and the tests being continued for from 20 to 60 minutes. Four tables give Experimental Results, Coefficients of Conductivity, Density of Materials, and Cost of Material per Unit Volume. Tables II. and III. are given on p. 524.

The original Paper should be consulted for description of the apparatus employed and for several practical considerations and deductions.

Discussion.—J. W. Cobb pointed out that the temperature of superheated steam induced carbonization and consequent ineffectiveness of some materials for covering steam pipes, and alluded to the effect of binding material and to the difference between air-spaces permitting and not permitting convection currents. The Author, in reply, promised another note on the use of binding materials and the insulation of steam pipes. Convection currents must be prevented. The value of an insulator depends on the real conductivity of the solid and on the volume and distribution of the contained air.

Coefficient of Conductivity (per 1° Cent.).

Air-dried Material.	Moisture per Cent. Loss at 100° C.	(a) B.Th U. per Square Foot per Hour.	(b) Calories per Square M. per Hour.
1. Slag wool (light)	0·2	0·054	0·045
2. Hair felt	7·3	0·058	0·048
3. Light magnesia	3·4	0·062	0·051
4. Granulated cork	4·0	0·069	0·057
5. Slag wool (heavy)	0·2	0·07	0·058
6. Kieselguhr	3·4	0·073	0·06
7. Flaky charcoal	4·7	0·082	0·068
8. Pumice	0·8	0·095	0·079
9. Sawdust (spruce)	9·0	0·096	0·08
10. Asbestos fibre	0·6	0·136	0·112
11. Sawdust (very moist) . . approx.	50·0	0·298	0·247
1. Air space with bright metallic surfaces and two layers of glazed paper intervening		0·077	0·064
2. Air space with bright metallic surfaces		0·093	0·077
3. Air space with dull-black surfaces		0·163	0·135

Density of Material.

Material.	(a) Weight in Lbs. per Cubic Foot.	(b) Weight in Kilos per Cubic Metre.
1. Granulated cork	6·1	98
2. Hair felt	7·9	127
3. Slag wool (light)	8·6	138
4. Light magnesia	10·1	167
5. Sawdust (spruce)	13·1	210
6. Flaky charcoal	14·5	233
7. Asbestos fibre	14·5	233
8. Kieselguhr	15·0	240
9. Pumice (small)	25·0	401
10. Slag wool (heavy)	32·9	527

F. J. R.

Boiler Economy. E. S. Farwell.

(Eng. Mag., 24, pp. 896–900, March, 1903.)

The Author discusses the fundamental principles which should govern boiler design, and advocates some radical changes. He maintains that in an ideal boiler plant, the furnace should be one in which the minimum amount of air requisite for complete combustion thoroughly percolates the fuel, and combustion is completed before the gases are cooled below the temperature of

ignition. The boiler, he considers, should be so designed as to present, at any point in the path of the gases, the maximum temperature difference between the gases and water, and to reject always and only the coolest gases. He advocates, wherever possible, the replacement of chimneys by power-fans, combined with utilization of the heat contained in the escaping gases, which latter may be much reduced by the suggested changes in design.

G. W. DE. T.

Motor-Car Lubrication. T. CLARKSON.

(Automobile Club Journ., 5, pp. 132–135; Discussion, pp. 135–137, Feb. 5, 1903. Paper read before the Automobile Club of Great Britain and Ireland, Jan. 30, 1903.)

The friction between two surfaces sliding together depends upon: (1) The pressure applied to them; (2) the material of the surface; (3) their smoothness and hardness; (4) their wetness and dryness; (5) their temperature; (6) the viscosity of the lubricating medium. The law that friction is independent of the extent of surface in contact needs qualification, for if the surface is large, the pressure per unit area may be insufficient to squeeze out the film of lubricant, but with relatively small wearing surfaces, the pressure may squeeze out the lubricant and permit contact which may become so intimate as to start "scoring" or tearing of the surfaces. A common arrangement of lubricators is for a pump to deliver the oil into a distributing main fitted with branch pipes which connect with the several bearings. The objection to this is that some of the branch pipes may become fouled after prolonged use, and the rest of the branches will obligingly take the blocked pipe's share; hence the Author designed a system by which the pump alternately works in full force on each pipe in turn, by means of a simple rotary valve closing all other pipes.

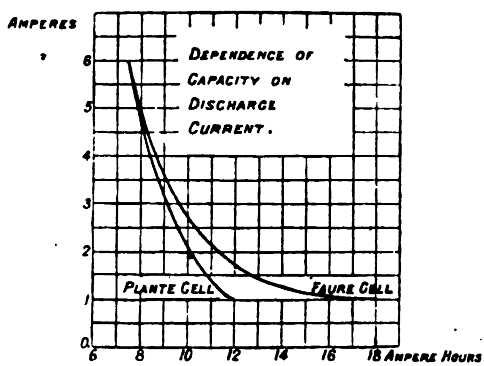
M. O'G.

Accumulator Tests. M. U. SCHOOP.

(Elektrotechn. Zeitschr, 24, pp. 214–218, March 19, 1903.)

The Author begins by criticizing the usual guarantees asked for when purchasing accumulators, among which, reference to the internal resistance of the cell is the exception, whereas, in certain cases, as in batteries for load-equalizing purposes, an accurate knowledge of the ohmic resistance is of great importance, standing as it does in close relationship to the boosting effect. Only recently it has become more usual to stipulate beforehand the maximum potential fall allowable when the battery has been

charged at maximum charging rate for a definite number of seconds and immediately afterwards discharged at the 1-hour rate for the same length of time. He instances, as an example of this, the Akkumulatoren-Fabrik A.G., who guarantee with their cells GS 21 to GS 84, that, for a discharge lasting $\frac{3}{4}$ minute at the 1-hour rate and a 1-minute charge at the same charging rate, the range of P.D. will be between 1·89 and 2·23 volts, with a maximum departure from this of ± 4 per cent. The Author then describes experiments carried out to decide the relative merits of formed and pasted plates, using for this purpose a modification of Uppenborn's Kohlrausch method of opposing the two test cells. The cells used were made up of plates having at the 1-hour discharge rate the same capacity down to the same .P.D, and differing from one another solely in the one having a formed positive and the other a pasted positive plate. The negatives were in both cases of the same construction and chosen of the same capacity, but possessing, relative to the positive plates, a large excess of capacity, so that the P.D. curve of the cells practically depended solely on the state of the positives. After several charges and discharges, the acid was replaced by fresh acid



of 1170, and the tests then begun. The data as to positives used are: Dry formed plate, weight 600 grammes (21 ounces), size in centimetres 10 by 12 by 0·7 (4 × 17 × 0·276 inches); pastod plate, weight 570 grammes (20 ounces), size in centimetres, 12 by 12 by 0·6 (4·7 × 4·7 × 0236 inches). With 6 amperes discharging current, the capacities were equal, but with slower discharge rates, the Faure cell utilized more and more of its active material, and at 1 ampere the capacities were already only as 2:3, as will be seen by the accompanying curve. Curves are also given from the electromotive force and P.D. readings. The Author then deals with the question as to which plate is the more suitable for buffer batteries, and gives curves embodying the results of further experiments which are fully described in the Paper. From these he draws the conclusion that with formed plates the

diffusion of the acid takes place more easily than with pasted plates (in the experiments described, the steady state of acid inter-diffusion from start of discharge took place in 10 minutes and 15 minutes repectively), so that with heavy discharges, the active material can be more fully utilized in the former than in the latter, but this is counterbalanced by the fact that the internal resistance of a pasted plate cell of the same capacity, acid strength, and plate separation is less than that of a cell with formed plates, and that therefore, from the buffer battery point of view, the pasted plate is undisputably superior.

L. H. W.

Experiments with a Pelton Wheel. W. C. Houston.

(Inst. Engin. and Shipbuilders, Trans., 46, 8, pp. 15–26, April, 1903.)

Experiments were made with a wheel 11·4 inches in diameter with different nozzles under varying heads, to determine the various losses. The ratio between the potential energy due to the head of water, called the available water horse-power, and the actual kinetic energy in the jet, was found to vary with the size of nozzle, but for any one size of nozzle, it was constant with pressures varying from 100 to 1,000 lbs. per square inch. The following values were obtained:—

Diameter of Nozzle. Inches.	Efficiency of nozzle.
0·0724	0·71
0·0835	0·80
0·1023	0·92

The other losses are those due to bearing and air friction, to the cups dividing the jet, to the edges of the cups interrupting the jet, and the residual energy in the water leaving the wheel. The frictional losses were determined by allowing the wheel to slow down from top speed, and calculating the resistance at any speed from the retardation and the calculated moment of inertia. The losses by cup friction, &c., were determined by taking the static couple, with the wheel fixed. The losses due to the edges of the cups are obtained by extrapolating the curve connecting brake readings and speed—the difference between the extrapolated brake reading when the speed is zero and the actual statical couple represents this loss. The residual energy in the water is calculated from the angles of the cups.

A. E. L.

Experiments with an Extra High-Tension Fuse. C. C. Garrard.

(Elect. Rev., 52, pp. 614–615, April 10, 1903.)

Circuit-breaking devices of the oil-break type are the only ones considered safe for extra high-tension circuits. The advantage of a fuse over an automatic switch is chiefly attributable to its introduction of the time element, its simplicity being a further recommendation. The experiments described were carried out with an oil-break fuse which was a development of the well-known Ferranti oil-break standard fuse. It consisted of a large porcelain pot 18½ inches high, having a central division piece, on which a porcelain saddle rested, dividing the pot into eight compartments. Contacts, projecting through the back, conducted current into and out of the fuse. Two spindles were connected to these contacts, and each spindle carried a number of drums containing springs, and fitted with flexible copper tapes long enough to reach to the top of the bridge. The tapes were drawn up from each side, against the tension of the springs, and fuse wires stretched between their ends across the dividing partition, a good contact being affected by soldering. When the wires melted, the flexibles were released and drawn quickly under the oil by the springs.

By permission of the Metropolitan Electric Supply Company, tests were made at Willesden Station, and the Sulzer-Kolben 5,500-HP. two-phase, 11,000-volt plant was used. The fuse, connected with an oil-break switch across one phase of the alternator, was fitted with 14 strands 28 LSG copper wire (giving a carrying capacity of 250 amperes). When the switch was closed, the phase was short-circuited through the fuse, which blew admirably, though a loud report was heard, and a cloud of smoke shot into the air.

The arc proved on examination to have been confined to one of the four parallel fuses, and the other wires were cut clean in two.

This action is advantageous in reducing the amount of vaporised metal in the arc, as only a quarter of the metal is vaporised in this case, as against the whole if the wires were bunched and fused together. The flash was not always confined to the same pair of flexibles, and a repetition of the tests was attended with similar results, no damage being done to the pot in any instance.

W. E. W.

Design of Continuous-Current Dynamos. H. A. Mavor.

(Inst. Elect. Engin., Journ., 32, pp. 473–484; Discussion, pp. 484–497, March, 1903.)

The Author gives a number of formulæ for determining the core and tooth losses, radiation from the surface of the core, and watts generated by the machine, its output and efficiency. He assumes

hysteresis and eddies in the core and hysteresis in the teeth, proportional to n, eddies in the teeth proportional to n^2, radiation proportional to $\sqrt{n}$. He shows that for every machine there is a maximum possible output for a given rise of temperature, and that this maximum is at a definite speed of rotation. The total watts and efficiency are greater for a low speed with a deep slot and high induction, and for a high speed with a shallow slot and high induction.

Discussion.—M. B. Field thought radiation should be expressed as $a + \beta \sqrt{n}$, and that eddies in the core should be taken as proportional to n^2. He pointed out that if the armature is short-circuited at very low speed the C^2R loss will equal the total permissible armature loss, or if it is open-circuited and run at a very high speed, the iron loss will equal the total permissible loss, the output in each case being zero. Between these speeds the output rises to a maximum and decreases again. He objected to the way some firms were standardising enclosed motors. They took a 20-HP. open motor and rated it at 15 or 10 HP. enclosed, without modification. The proportion of iron to copper loss could not be the best in each case. W. A. Ker said the practice of his company was to enclose their ordinary open motor, and run it at a lower rating at a lower speed. By reducing the speed from 1,000 to 900 with a smaller current, it is possible to add at least one turn to each commutator section without increasing the reactance voltage. He thought that the watts radiated should be proportional to the speed. W. B. Hird thought that, within ordinary limits of speed, the formula $a \sqrt{n}$ might express the watts radiation just as well as $a + \beta \sqrt{n}$; and that it was sufficiently accurate to take the core eddies as a percentage of the core hysteresis, except at very high speeds. The Author in reply, said it was necessary in small machines to consider the speed at which the machine had to run with special reference to the iron losses. His method was to plot the watts radiated at each speed with the iron losses. He agreed that it might be better to plot the curves of watts radiated, as Field suggested.

R. B. R.

Speed-Control of Electric Motors on Constant-Pressure Mains.

W. B. Sayers.

(Inst. Engin. and Shipbuilders, Trans., 46, 6, pp. 43–58; Discussion, pp. 58–64, March, and 46, 8, pp. 4–14, April, 1903)

The output limit of a motor when speed is varied by varying excitation is a constant quantity, since the maximum armature current must remain practically constant, and the torque vary as the product of current into magnetic field. For a variable speed

motor, the size in HP. = size in HP. of standard speed motor to do the maximum work $\times \frac{\text{maximum speed}}{\text{minimum speed}}$, and the efficiency = 100 — x × percentage losses of motor at standard speed and output $\times \frac{\text{standard output}}{\text{variable speed output}}$. The Author gives a table of sizes of motor required, in terms of rated HP. at normal speed, for speeds variable through ranges of 15 per cent., 33 per cent. 2 to 1 and 3 to 1. He discusses the effect of variable speed on the efficiency, giving figures for the various losses at different speeds.

Discussion.—H. A. Mavor said the prime point in the matter was the commutator difficulty, and the whole thing depended on the reactance voltage. The reactance voltage per section = watts input × turns per section × magnetic field produced by winding per Cr length of wire ÷ diameter of armature × average density of flux in air space, taken over the whole surface of the armature. Henry Lea gave figures relating to cost and efficiency of some 5, 6, and 7½-HP. motors driving fans at 600 to 900 revolutions. W. A. Chamen mentioned a system devised by A. H. Pott. The proposal was to have, say, 300 volts between one outer and the middle wire of a three-wire system, and 200 volts between the middle and the outer, giving three different voltages. A further variation might be obtained by using a double-ended armature, the two windings to be used either in series or in parallel. W. L. Spence described a 460-volt, 5-wire system giving the following pressures: 95, 135, 190, 230, 325 and 460. M. M'Lean thought the method of putting resistance in the armature should not be summarily dismissed, for variations of speed not exceeding 20 to 30 per cent. The percentage reduction of speed would not be very different from the percentage reduction of efficiency. T. B. Murray said the difficulty with brushes could be got over, to a certain extent, by using multiple brushes. He mentioned a double-wound armature with two commutators, introduced first by Messrs. Egger, of Vienna. This was very useful for motor car work. He found it advisable not to rely on carbon brushes for reversing, but he had used a system of reversing magnets energised by the main current. The Author, in reply, pointed out that if series resistance was used, the capacity of the motor to maintain constant speed with variable load was ruined.

R. B. R.

Transformers in Transmission Systems. A. D. ADAMS.

(Elect. Rev., N.Y., 42, pp. 496–498, April 11, and pp. 535–536, April 18, 1903.)

The writer describes static transformer practice in America. For transmission over less than 15 miles it is generally better to avoid the use of transformers at generating stations. Generators

up to 13,500 volts are now regularly manufactured. Generators giving from 10,000 volts to 13,500 volts are employed at Manchester, N.H., Lewiston, Me., and Salem, N.C. But for distances exceeding 25 miles step-up transformers are employed. 50,000 to 60,000 volt transmission lines represent present highest practice—Colgate to Oakland and San Francisco, 40,000 volts; Cañon Ferry, on the Missouri River, to Butte 50,000 volts. The writer then discusses the relative groupings employed for generators and transformers and their relative capacities, and gives practical cases where these various combinations have been installed. Three-phase transformers are practically not yet used in the United States, the arrangement almost invariably consisting of groups of three single-phase transformers. The writer notes the strong tendency towards decreased frequencies, and comments on some of the advantages. Transformers of 100 kilowatt capacity and upwards (in present practice single transformers of over 1,000 kilowatt capacity are frequently met with) employ artificial cooling by water-pipes in oil and by cooling dry transformers by means of an air-blast. In a substation at Manchester, N.H., twenty-seven 200 kilowatt transformers which are cooled by air-blast require less than 1 H.P of motor capacity for each 200 kilowatt capacity in transformers. Where a motor-driven blower is employed per group of transformers, it is a common practice to lead the air directly from each blower to the group of transformers by a metal duct, thus avoiding the necessity for an air chamber. In such cases, a blower giving a three-eighth-ounce air pressure per square inch, and a motor of 1 HP. capacity, are generally installed for each group of three transformers of some 125 kilowatt capacity each. As to water-cooling, one manufacturer estimates that the amount required (supplied at 15° C.) to be forced through the transformers to prevent a rise of more than 35° above air when operating under full load, would be—

Kilowatts Total Capacity of Transformers.	Gallons of Water required per Minute.
75	0·37
150	0·50
400	0·75
600	1·00
1,000	1·5

The writer cautions against maintaining artificially-cooled transformers at a temperature lower than that of the surrounding air, lest harm result from condensation upon its parts. In connection with possible subdivision of secondaries into distinct coils for feeding independent systems, a plant is mentioned at Manchester, N.H., where a novel and interesting arrangement is employed. Each of a group of three single-phase transformers fed from a three-phase circuit, has two independent secondaries. Three of these secondaries, one on each transformer, are connected together and supply a 380-volt three-phase rotary converter. The other three secondary windings are

2 M 2

connected in like manner to a second rotary converter. Each of these transformers is rated at 250 kilowatts, and each rotary is rated at 300 kilowatts, so that the transformer capacity amounts to 750 kilowatts, and that of the converters to 600 kilowatts. Amongst the rather large number of plants by which the writer illustrates his statements and conclusions, three in particularly are frequently referred to, and the data of these three plants, so far as could be gathered from the article, may be summarised as follows: *Data of Transmission Plants.*—Apple River to St. Paul: At generating station, which contains four 750-kilowatts three-phase 800-volt generators, there are six 500-kilowatt transformers connected in two sets of three each, and at the substations six 300-kilowatt and four 200-kilowatt transformers, the transmission being effected at 25,000 volts. Colgate to Oakland (and San Francisco): Three 1,125-kilowatt and four 2,250-kilowatt three-phase 2,300-volt, 60-cycle generators and step-up transformers in 700-kilowatt units, arranged in Y connected groups, are employed. Each transformer has three sets of taps brought out from its secondary coils, permitting of obtaining line voltages of 40,000, 50,000, or 60,000 volts; the higher voltages will, it would seem, be employed later as the load increases. Cañon Ferry to Butte: The electrical generating plant consists of ten 750-kilowatt 550-volt 60 ~ three-phase generators. By means of six 950-kilowatt Δ-connected transformers, the power is stepped up to 50,000 volts and transmitted to a substation at Butte. Two transmission circuits are provided for this purpose. The six 950-kilowatt transformers in the Butte substation are arranged in two groups. The generating station also contains twelve 325-kilowatt transformers arranged in four groups of three each, and supplying substations at Helena. The total capacity of step-up transformers is—apparently, the writer states, in the interests of regulation—9,600 kilowatt, as against a capacity of only 7,500-kilowatts in generators.

H. M. H.

Central Power-Stations in Europe. L. GERARD.

(Soc. Belge. Elect., Bull., 20, pp. 177–178, April, 1903.)

The author, after referring to the mistaken idea that large water-power stations are only to be found in America, gives some details concerning the Vizzola generating station: one of the most important generating stations of this type in operation in Europe. He then passes on to consider the prospects of central power-stations relying upon coal and steam power. As regards the Vizzola Power Station the author states that 22,000 H.P. has been developed with a capital expenditure of 40,000,000 francs. The comparison of costs for electrical power generated from water and coal respectively. is based chiefly upon figures which have been

published by Saint Martin in a recent book upon "Les Distributions d' Energie Electrique." This author states that the capital expenditure per kilowatt of plant installed in steam-driven stations, varies from 600 to 1,600 francs, according to the size and scale of the station. The corresponding figures for water-power stations are given as 2,200 and 2,700 francs. As an example of the costs of water-power development in France, Saint Martin cites the figure for the station of the Société de Jouage à Lyon, where 20,000 kilowatts have been developed at a cost of 40,000,000 francs. As regards tariffs, Saint Martin has given the following figures for water-power in Switzerland.

	Francs per HP. per Annum.
For motors using $\frac{1}{10}$ to 1 HP.	300–250
" " " 30 to 50 "	200–150
" " " 50 to 100 "	150–120

In the district of St. Etienne, in France, electric power is sold at a price ranging from 300 to 600 francs per H.P. per annum; while the Société Jouage à Lyon has a tariff which ranges from 120 francs to 360 francs. Saint Martin believes, in the light of these figures, that a central station, driven by steam, could produce electric power as cheaply as (and therefore compete with) these large central water-power stations. Taking the capital expenditure and present receipts of two typical generating stations of this type, we have the following comparison.

	Capital Expenditure. Francs.	Receipts. Francs.
Water Power	50,000,000	2,277,762
Steam Power	12,000,000	1,300,000

The first of these stations has a tariff higher than that of a number of small steam-driven generating stations in the same district, and has a difficulty in even meeting its standing charges. The second operates on an absolutely economic basis, and returns a dividend on its capital. The author concludes by stating his belief that central power-stations driven by steam, if well planned and wisely situated as regards supplies of coal and distribution of current, can compete on favourable terms with water-power stations; and expresses his confidence in the future of coal for the generation of electrical energy in the coal-bearing districts of Europe. J. B. C. K.

Power-Station Arrangement for Electrically Operating Steam Railways. C. J. Spencer.

(Elect. World and Engineer, 41, pp. 272–273, Feb. 14, 1903.)

The author discusses the relative merits of centralising the power plant, distribution by high-tension alternating current to substations, and the continuous- current system with several

generating stations spaced at certain distances along the line. He advocates continuous-current stations, with accumulators, generating at 600 volts, spaced along the road ten miles apart, with accumulator houses between every two generating stations. With the distributing system of stations there is greater immunity from break down, and no more reserve machinery would be necessary than in the central station system.

F B.

INDEX

TO THE

MINUTES OF PROCEEDINGS,

1903-1904.—PART I.

N.B.—Titles in italics refer to Original Papers, and those selected for printing only are further distinguished by the suffix "(S.)." Abstracted Papers are not so indicated.

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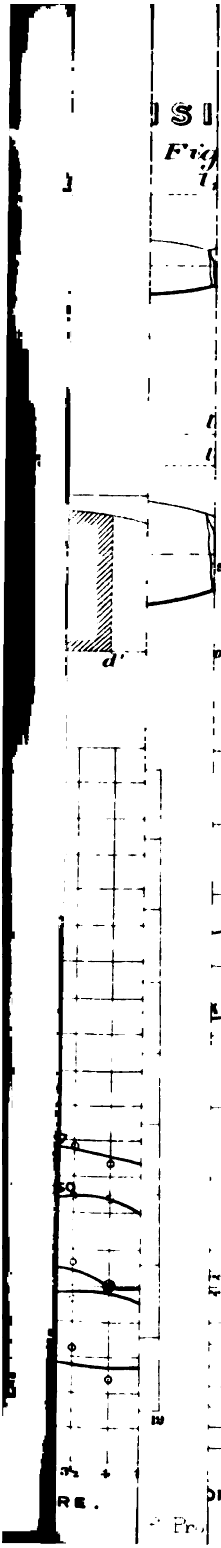
p. 552a

PLATE I.



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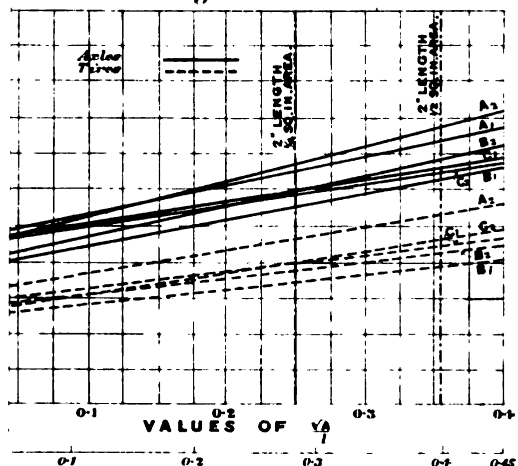
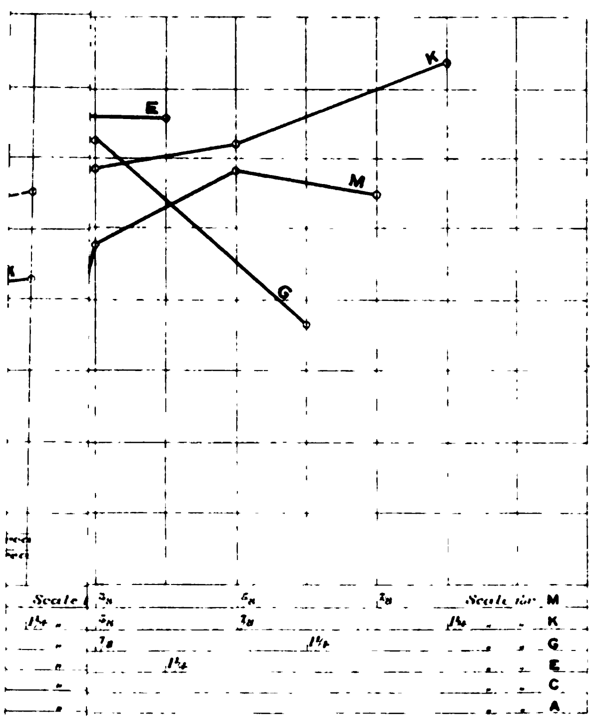


SHORT TURNED TEST-BARS.



NAL AR OF THE SAME WIDTH, VIZ., 2")

THOS KELL & SON, LITH. 40 KING ST COVENT GAR

PLATE 2.

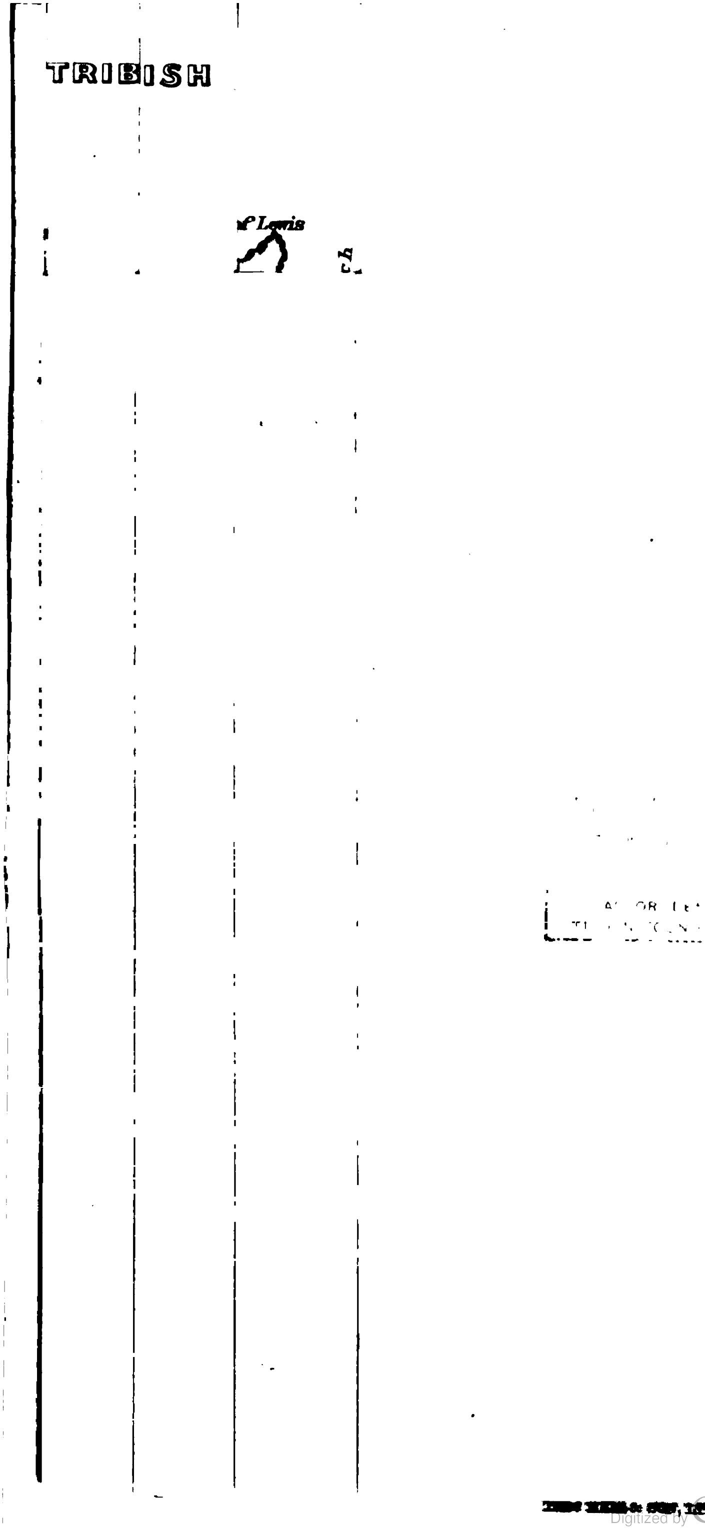


PLATE 3.

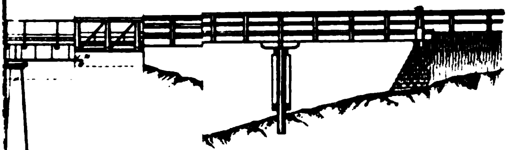
Fig: 6.

EXTREMUM RAINFALL IN THE PERIOD 1870—99.

THOS KELL & SON, LITH. LONDON.

RI

F



TAB

SC 28'

IN 16

S 2 ind 7

13

1

40

12

3

17

4

F

23'

2"

CONC

F

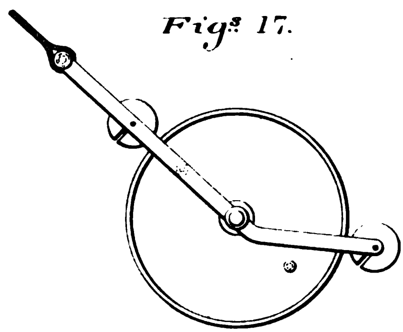
12" x 13"

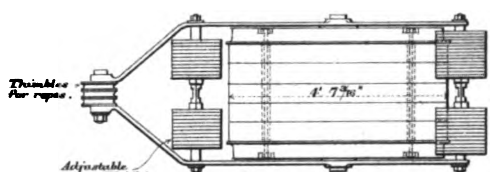
DNCR

CHORI

OSS

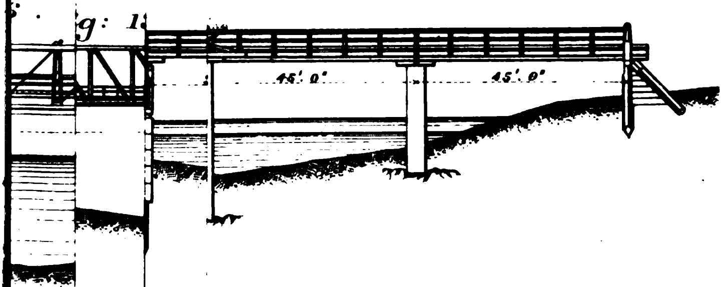
Fig. 17.





BALANCE WEIGHT.

g: 1

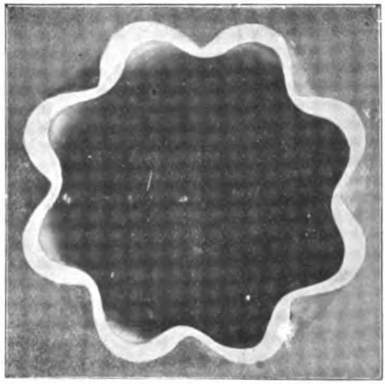


GE B

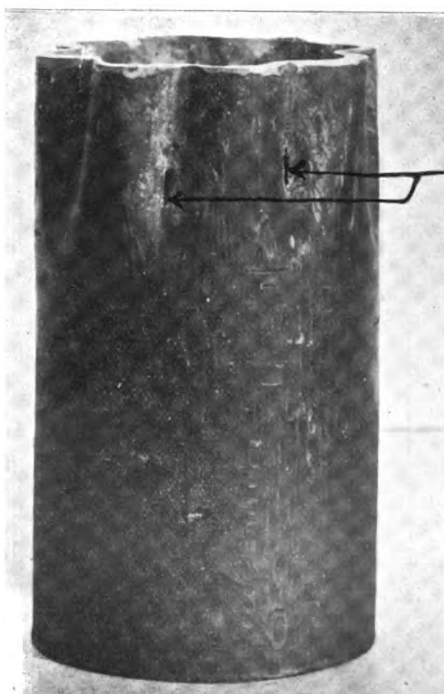
roceedi

THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN.

Figs. 5.



CROSS-SECTION OF WORN FLUTED TUBE.



ELEVATION OF END OF WORN FLUTED TUBE.

TU

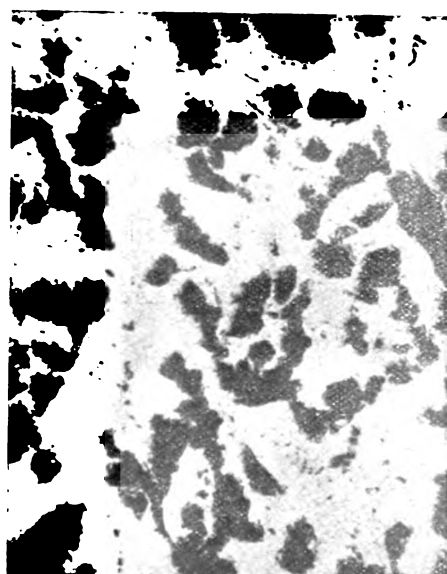
154 CU

B FROM

FIG. 15

E--AFTER ANNEALING.

FIG. 16.



C—AFTER ANNEALING.